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(12) **United States Patent**
Fair

(10) **Patent No.: US 9,152,503 B1**
(45) **Date of Patent: *Oct. 6, 2015**

(54) **SYSTEM AND METHOD FOR EFFICIENTLY CALCULATING STORAGE REQUIRED TO SPLIT A CLONE VOLUME**

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(73) Assignee: **NetApp, Inc.**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1048 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/783,664**

(22) Filed: **May 20, 2010**

Related U.S. Application Data

(63) Continuation of application No. 11/082,098, filed on Mar. 16, 2005, now Pat. No. 7,757,056.

(51) **Int. Cl.**
G06F 12/00 (2006.01)
G06F 11/14 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 11/1448*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 11/1446–11/1453
USPC 711/170
See application file for complete search history.

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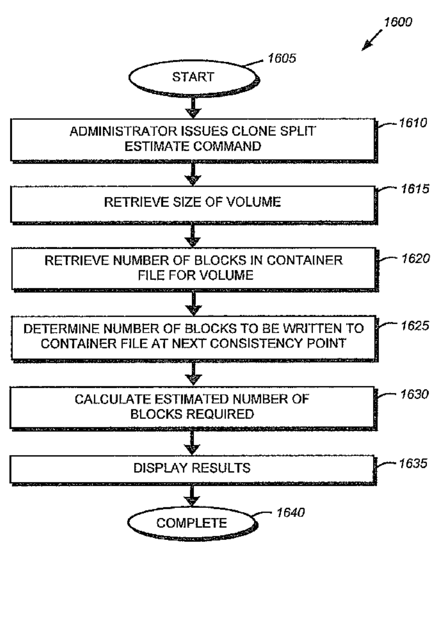
(57) **ABSTRACT**

A system and method efficiently calculates an estimated amount of storage required to split a clone volume from its parent volume. The system and method is illustratively embodied as a command line interface (CLI) command, i.e., a clone split estimate command, executed by an estimation module of a storage system. Notably, the estimation module cooperates with a file system of the storage system to quickly access data structures containing information used to perform the storage calculation without the need to access each block of the clone and parent volumes.

29 Claims, 15 Drawing Sheets



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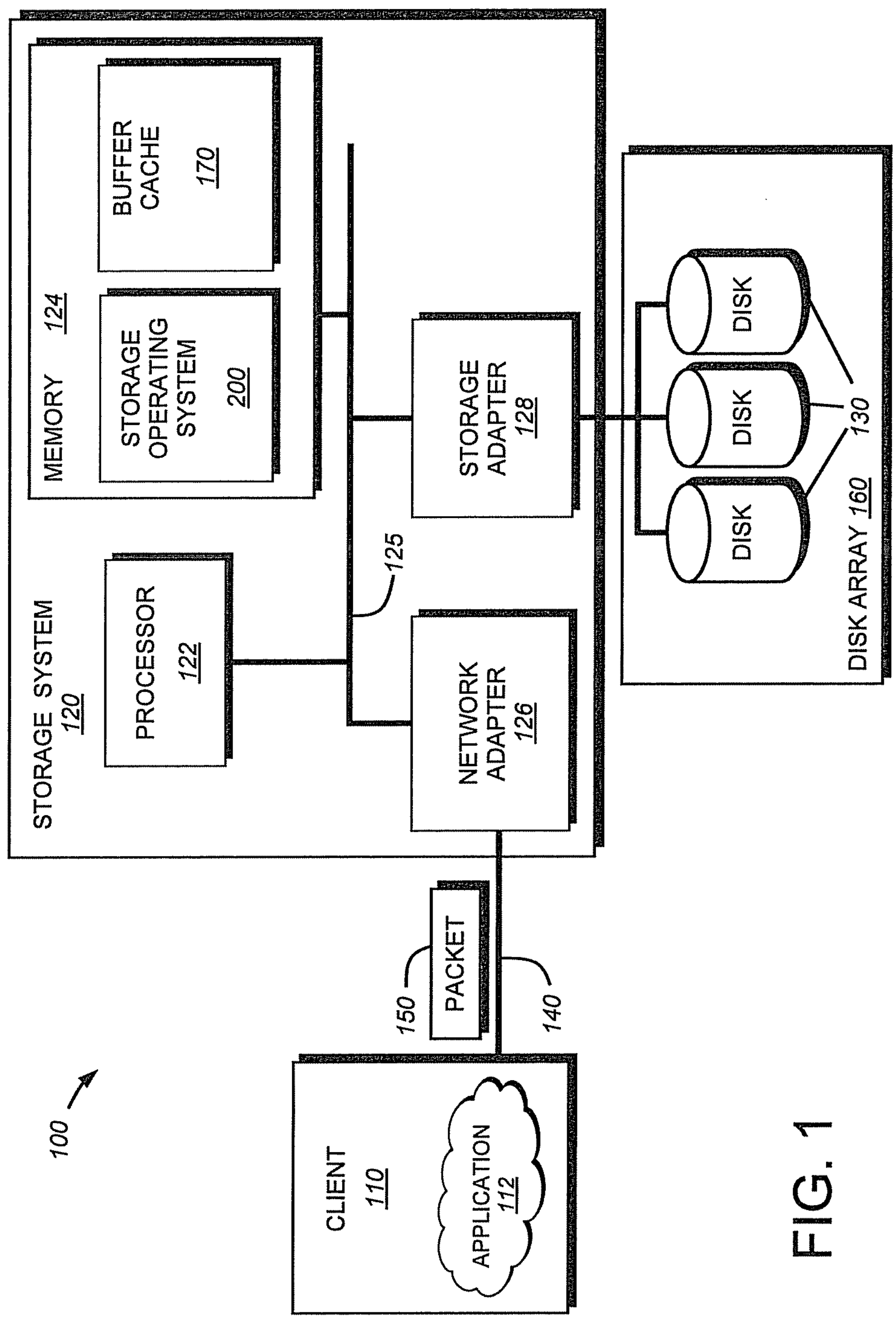
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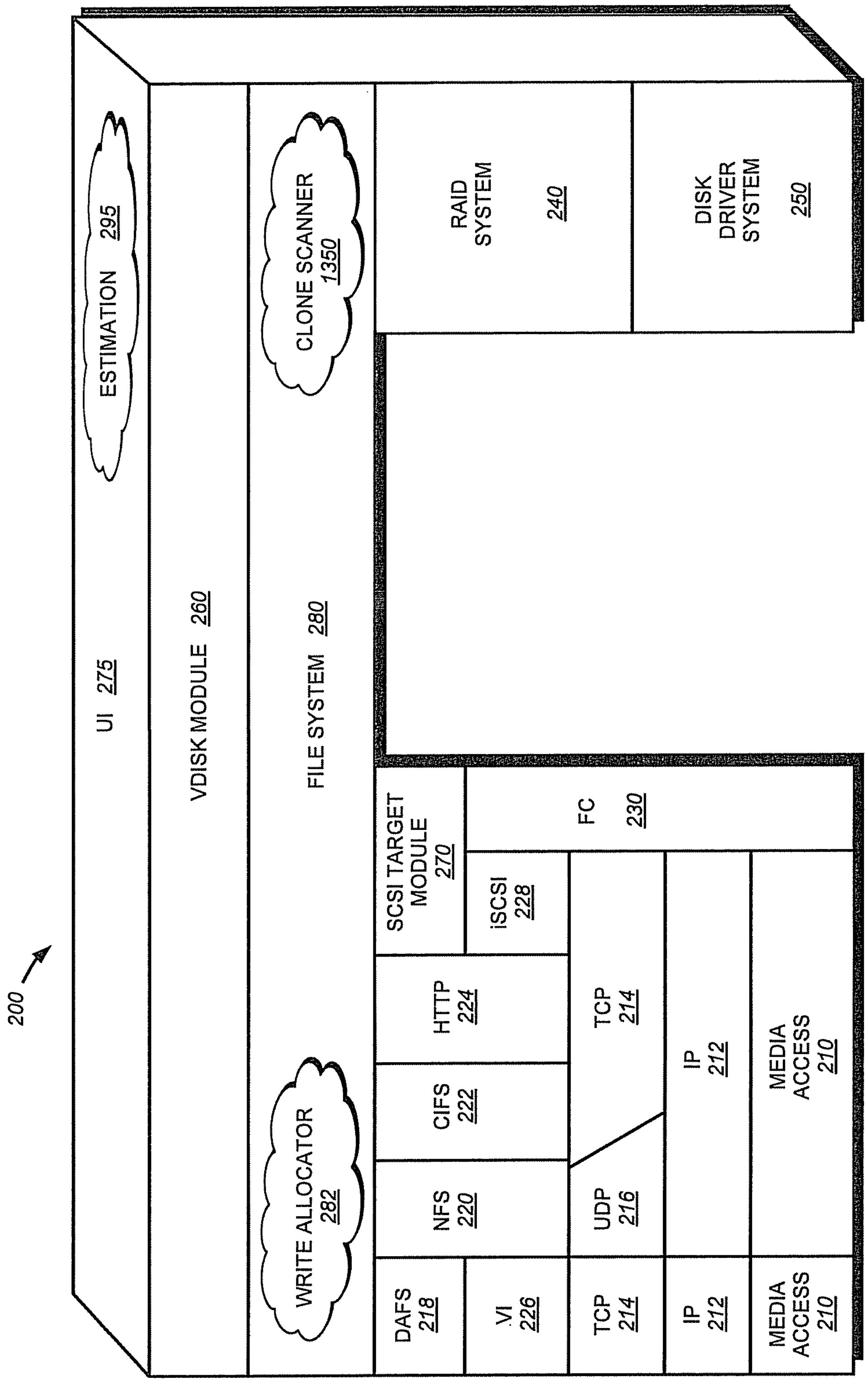
MEMORY 124
STORAGE OPERATING SYSTEM 200
BUFFER CACHE 170
125
NETWORK ADAPTER 126
STORAGE ADAPTER 128
DISK
DISK
DISK
130
DISK ARRAY 160
PACKET
150
140
CLIENT 110
APPLICATION 112

FIG. 1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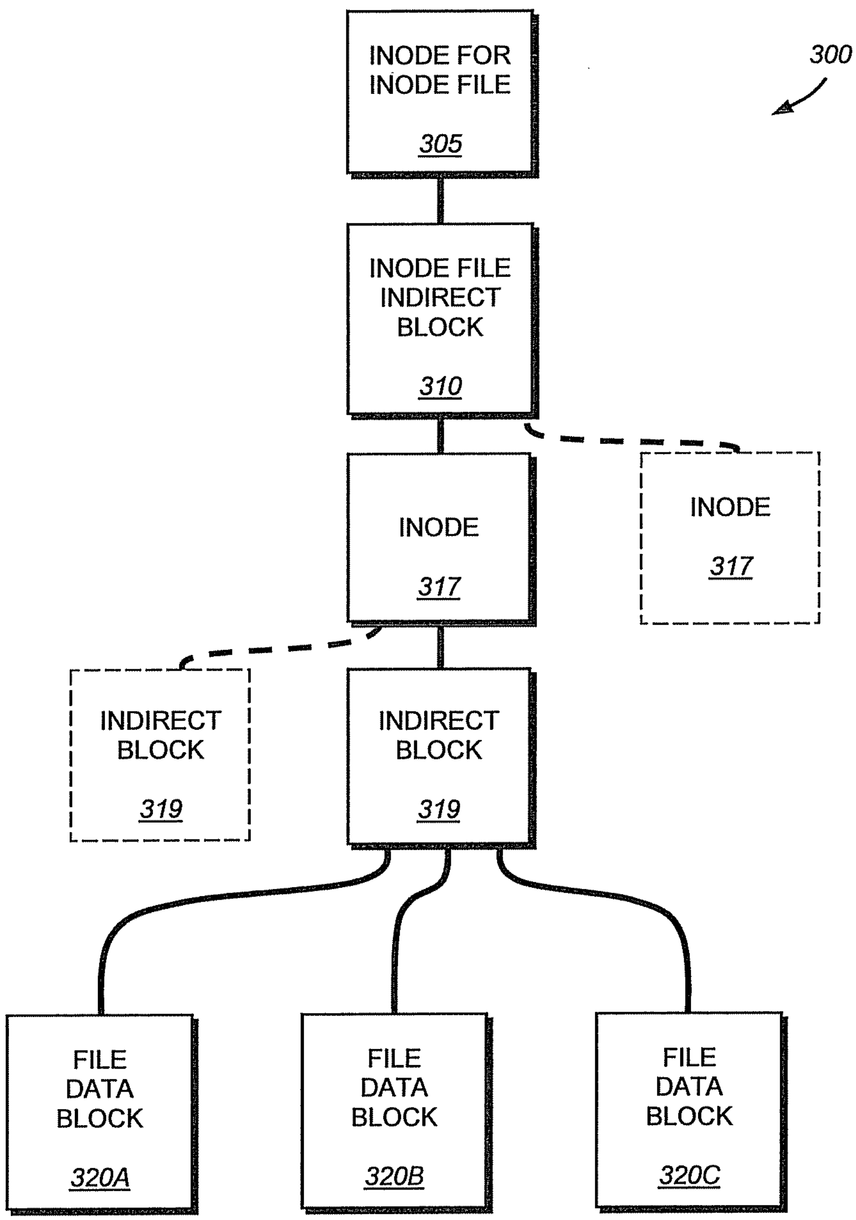
VDISK MODULE 260
FILE SYSTEM 280
CLONE SCANNER 1350
WRITE ALLOCATOR 282
RAID SYSTEM 240
DISK DRIVER SYSTEM 250
SCSI TARGET MODULE 270
FC 230
iSCSI 228
HTTP 224
CIFS 222
NFS 220
DAFS 218
VI 226
TCP 214
UDP 216
IP 212
MEDIA ACCESS 210
TCP 214
IP 212
MEDIA ACCESS 210

FIG. 2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305
INODE FILE INDIRECT BLOCK
310
INODE
317
INODE
317
INDIRECT BLOCK
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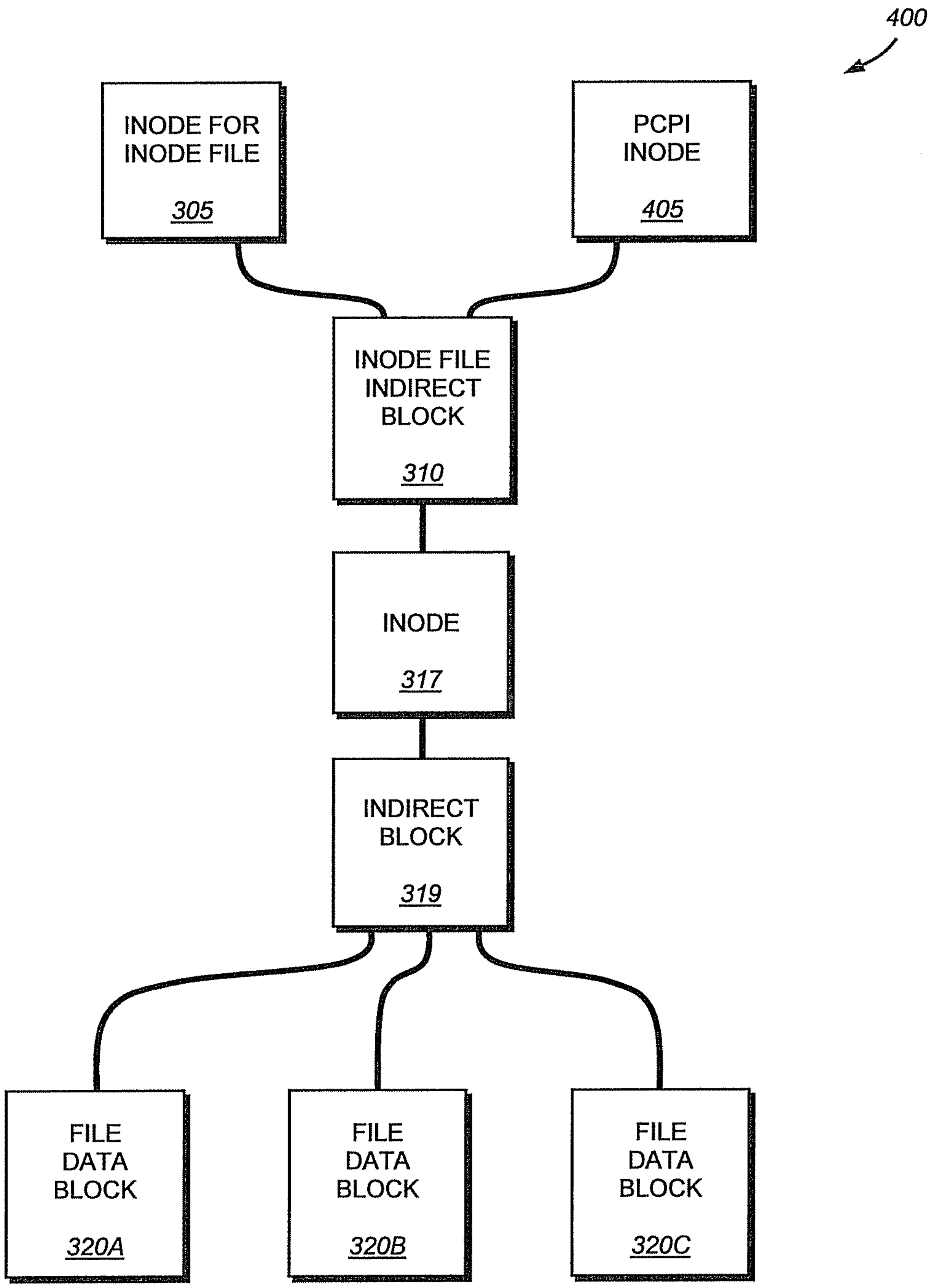
INDIRECT BLOCK
319
FILE DATA BLOCK
320A
FILE DATA BLOCK
320B
FILE DATA BLOCK
320C

FIG. 3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FILE DATA BLOCK
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FILE DATA BLOCK
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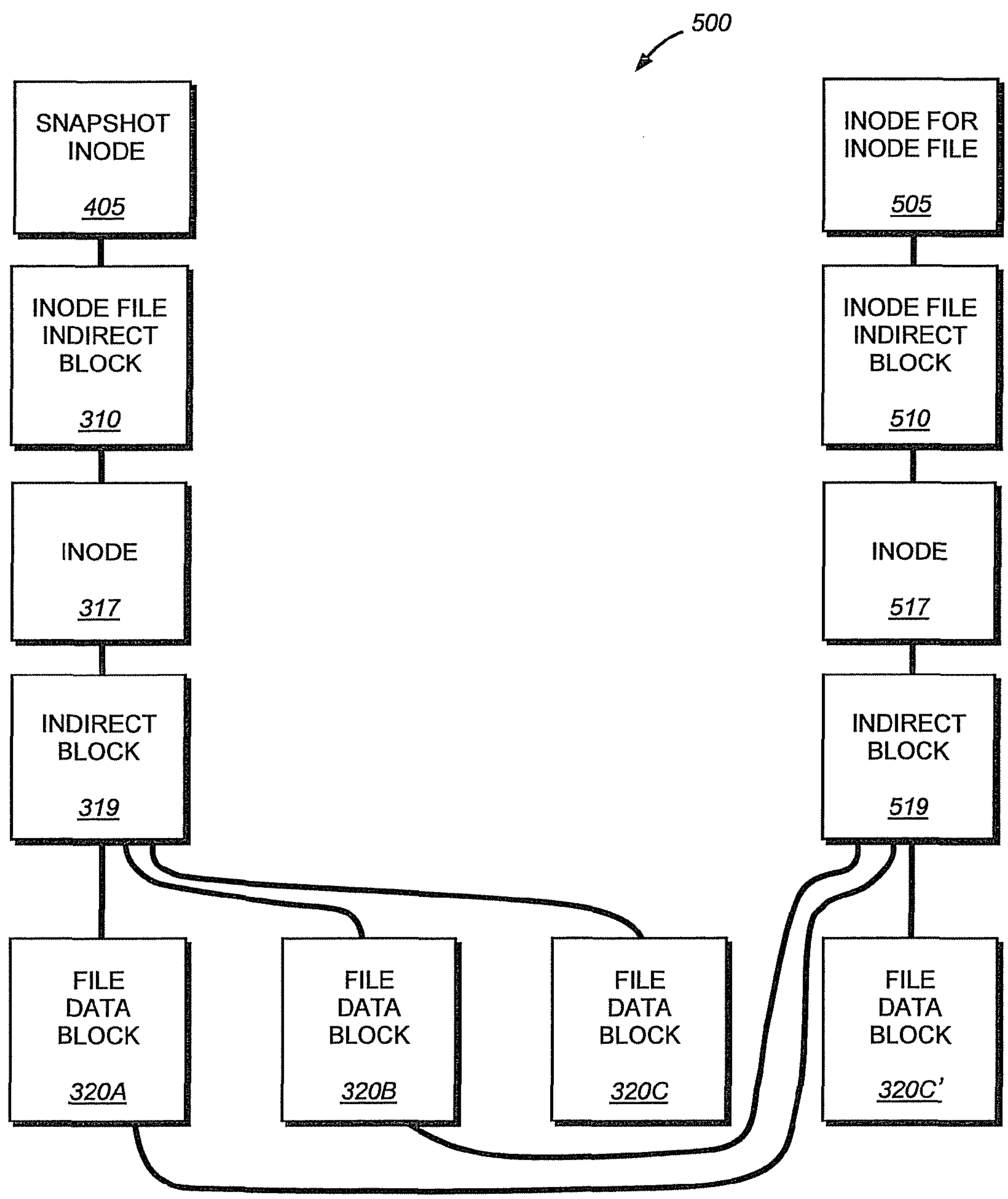
FIG. 4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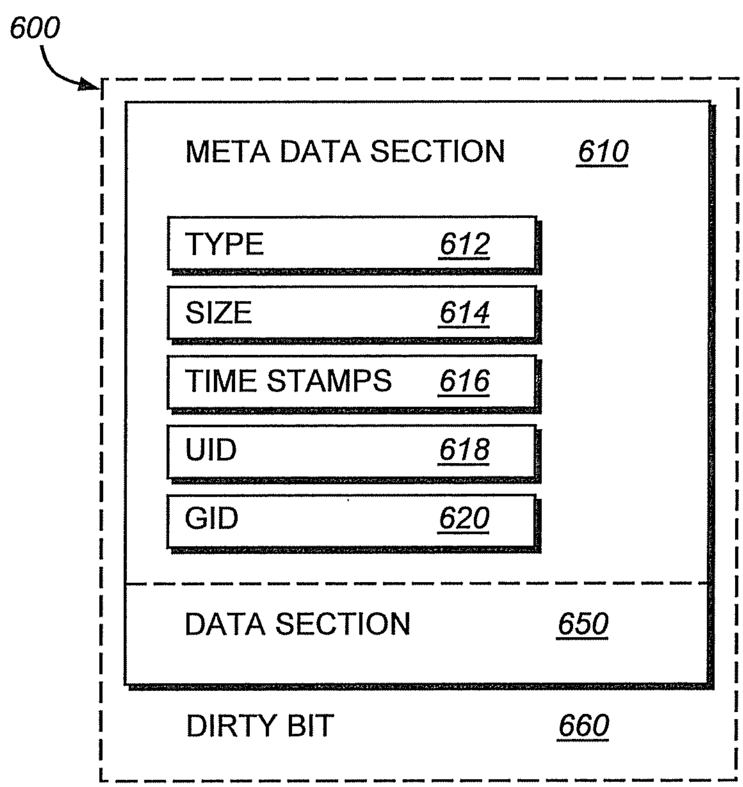
FILE DATA BLOCK
320C
FILE DATA BLOCK
320C'

FIG. 5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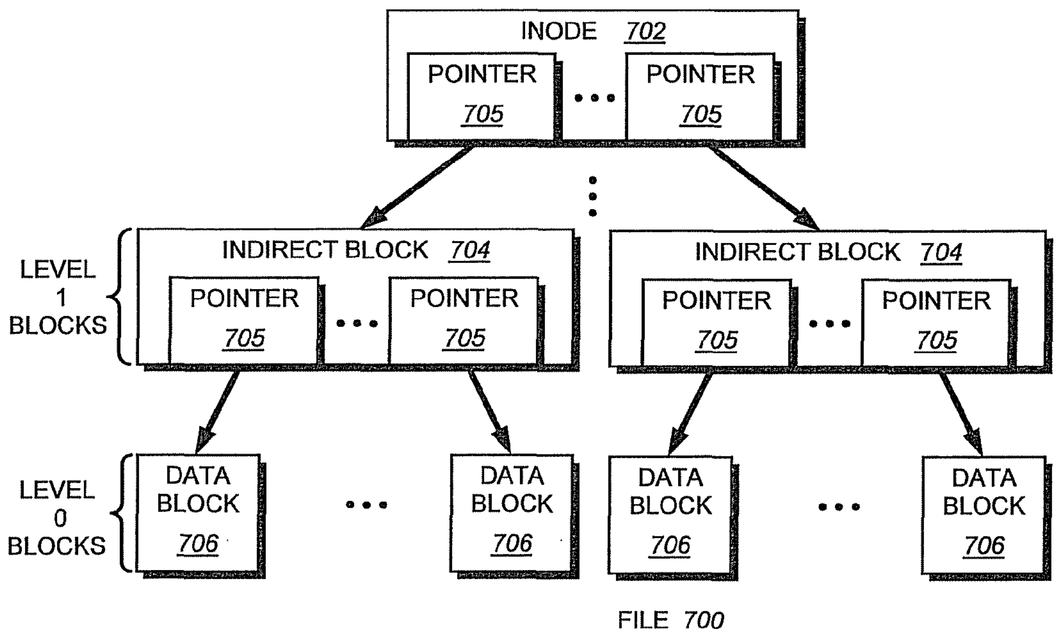
GID 620
DATA SECTION 650
DIRTY BIT 660

FIG. 6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POINTER 705
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LEVEL 1 BLOCKS
POINTER 705
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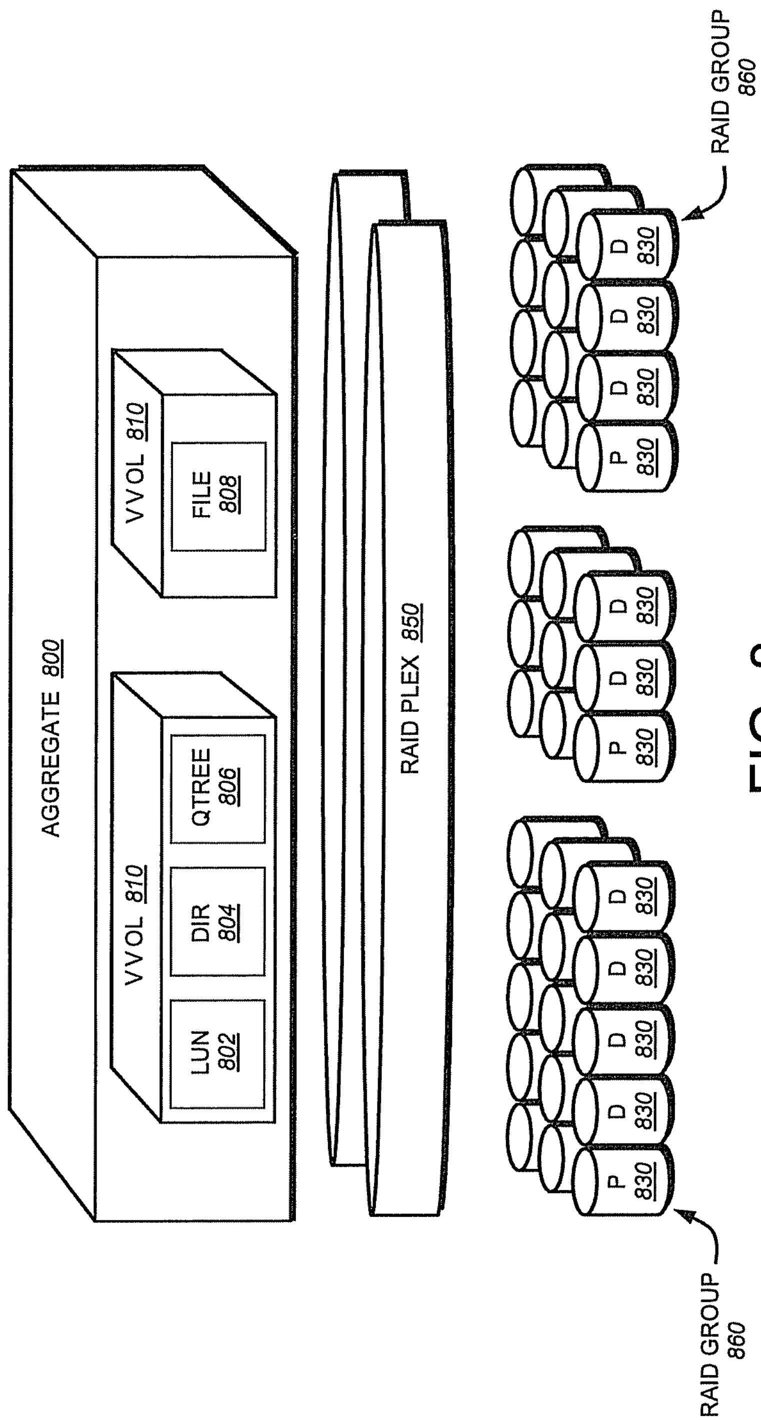
DATA BLOCK 706
DATA BLOCK 706
DATA BLOCK 706
FILE 700

FIG. 7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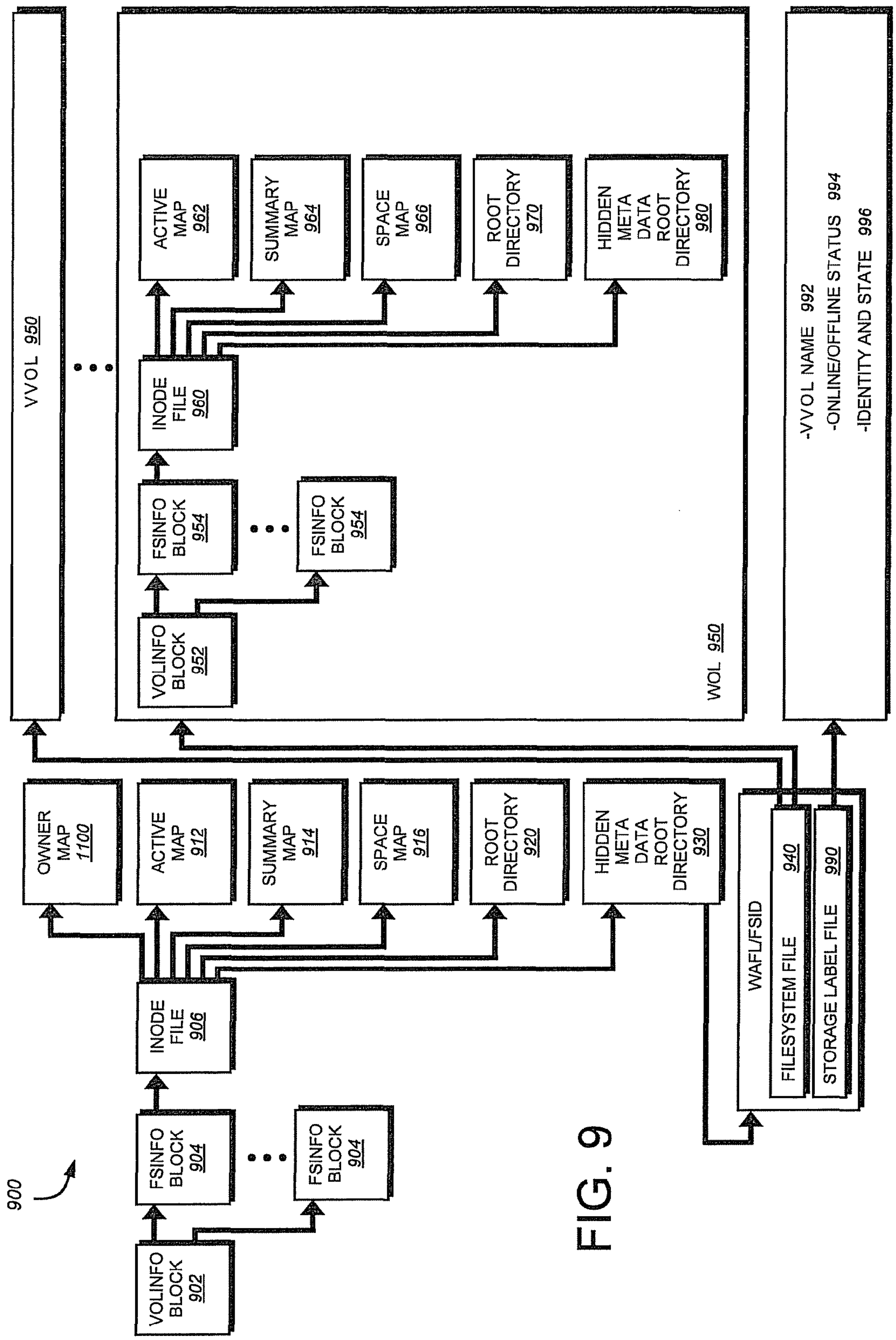
RAID GROUP 860

FIG. 8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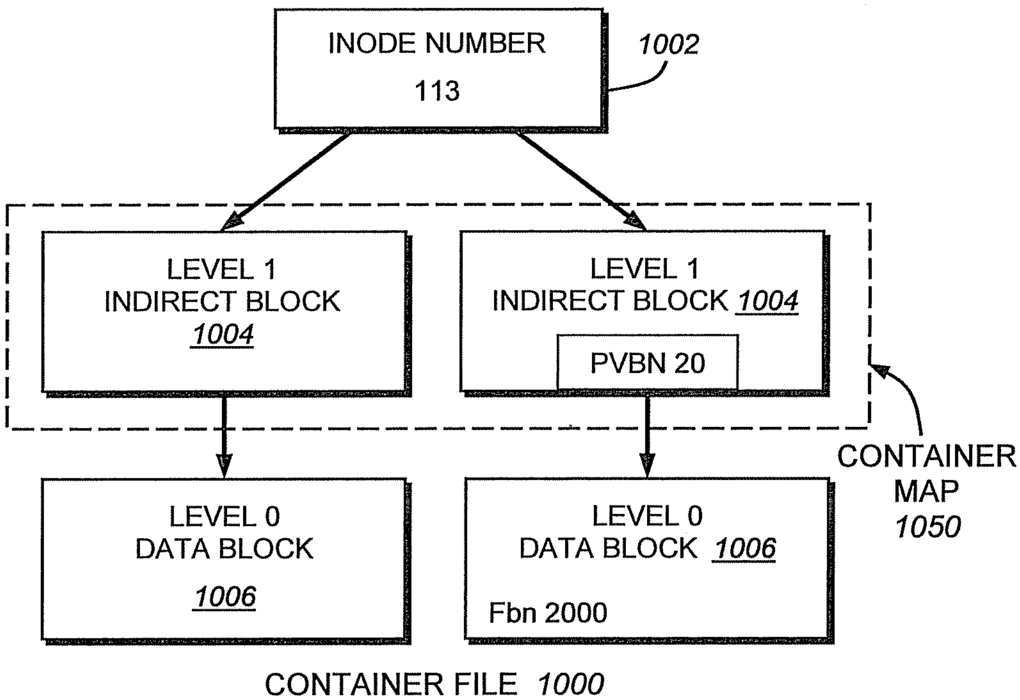
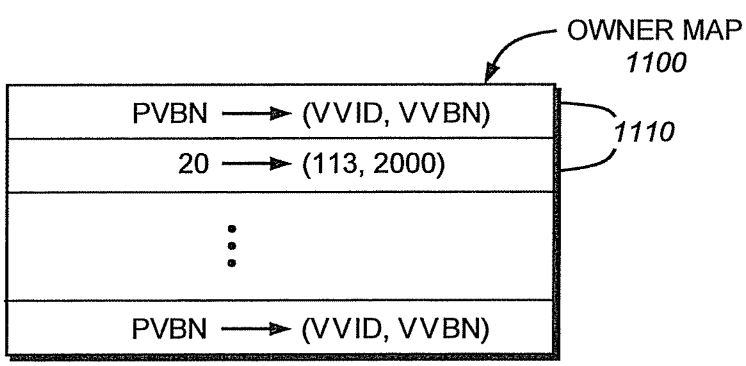
FSINFO BLOCK 904
FSINFO BLOCK 904
INODE FILE 906
OWNER MAP 1100
ACTIVE MAP 912
SUMMARY MAP 914
SPACE MAP 916
ROOT DIRECTORY 920
HIDDEN META DATA ROOT DIRECTORY 930
WAFL/FSID
FILESYSTEM FILE 940
STORAGE LABEL FILE 990
VVOL 950
VOLINFO BLOCK 952
FSINFO BLOCK 954
FSINFO BLOCK 954
INODE FILE 960
ACTIVE MAP 962
SUMMARY MAP 964
SPACE MAP 966
ROOT DIRECTORY 970
HIDDEN META DATA ROOT DIRECTORY 980
WOL 950
-VVOL NAME 992
-ONLINE/OFFLINE STATUS 994
-IDENTITY AND STATE 996

FIG. 9



INODE NUMBER
113
1002
LEVEL 1
INDIRECT BLOCK
1004
LEVEL 1
INDIRECT BLOCK 1004
PVBN 20
CONTAINER
MAP
1050
LEVEL 0
DATA BLOCK
1006
LEVEL 0
DATA BLOCK 1006
Fbn 2000
CONTAINER FILE 1000

FIG. 10



OWNER MAP
1100
PVBN → (VVID, VVBN)
20 → (113, 2000)
1110
PVBN → (VVID, VVBN)

FIG. 11

11/15

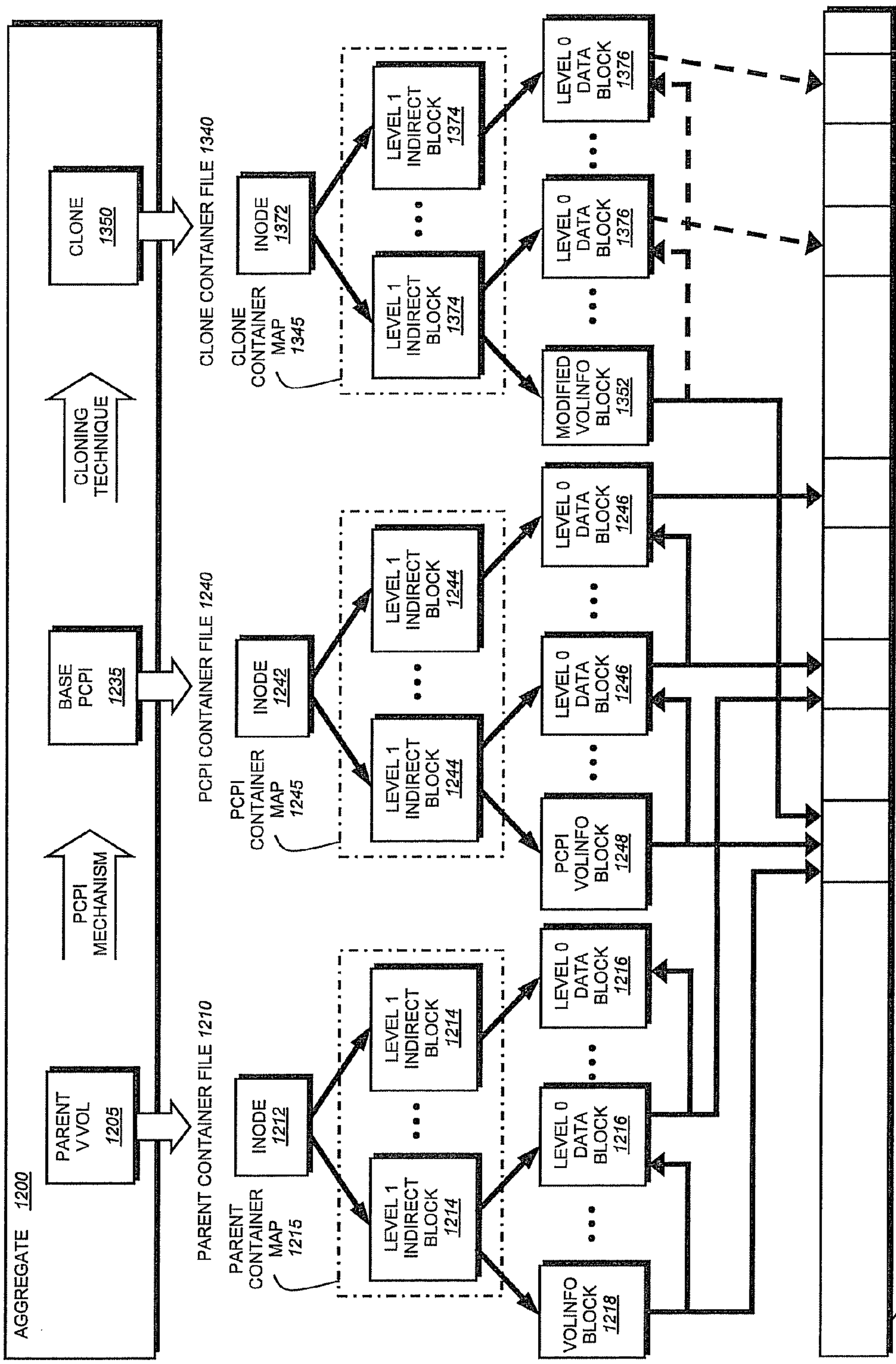

AGGREGATE 1200
PARENT VVOL 1205
PCPI MECHANISM
BASE PCPI 1235
CLONING TECHNIQUE
CLONE 1350
PARENT CONTAINER FILE 1210
PARENT CONTAINER MAP 1215
INODE 1212
LEVEL 1 INDIRECT BLOCK 1214
LEVEL 1 INDIRECT BLOCK 1214
VOLINFO BLOCK 1218
LEVEL 0 DATA BLOCK 1216
LEVEL 0 DATA BLOCK 1216
PCPI CONTAINER FILE 1240
PCPI CONTAINER MAP 1245
INODE 1242
LEVEL 1 INDIRECT BLOCK 1244
LEVEL 1 INDIRECT BLOCK 1244
PCPI VOLINFO BLOCK 1248
LEVEL 0 DATA BLOCK 1246
LEVEL 0 DATA BLOCK 1246
CLONE CONTAINER FILE 1340
CLONE CONTAINER MAP 1345
INODE 1372
LEVEL 1 INDIRECT BLOCK 1374
LEVEL 1 INDIRECT BLOCK 1374
MODIFIED VOLINFO BLOCK 1352
LEVEL 0 DATA BLOCK 1376
LEVEL 0 DATA BLOCK 1376
DISK 1220

FIG. 12

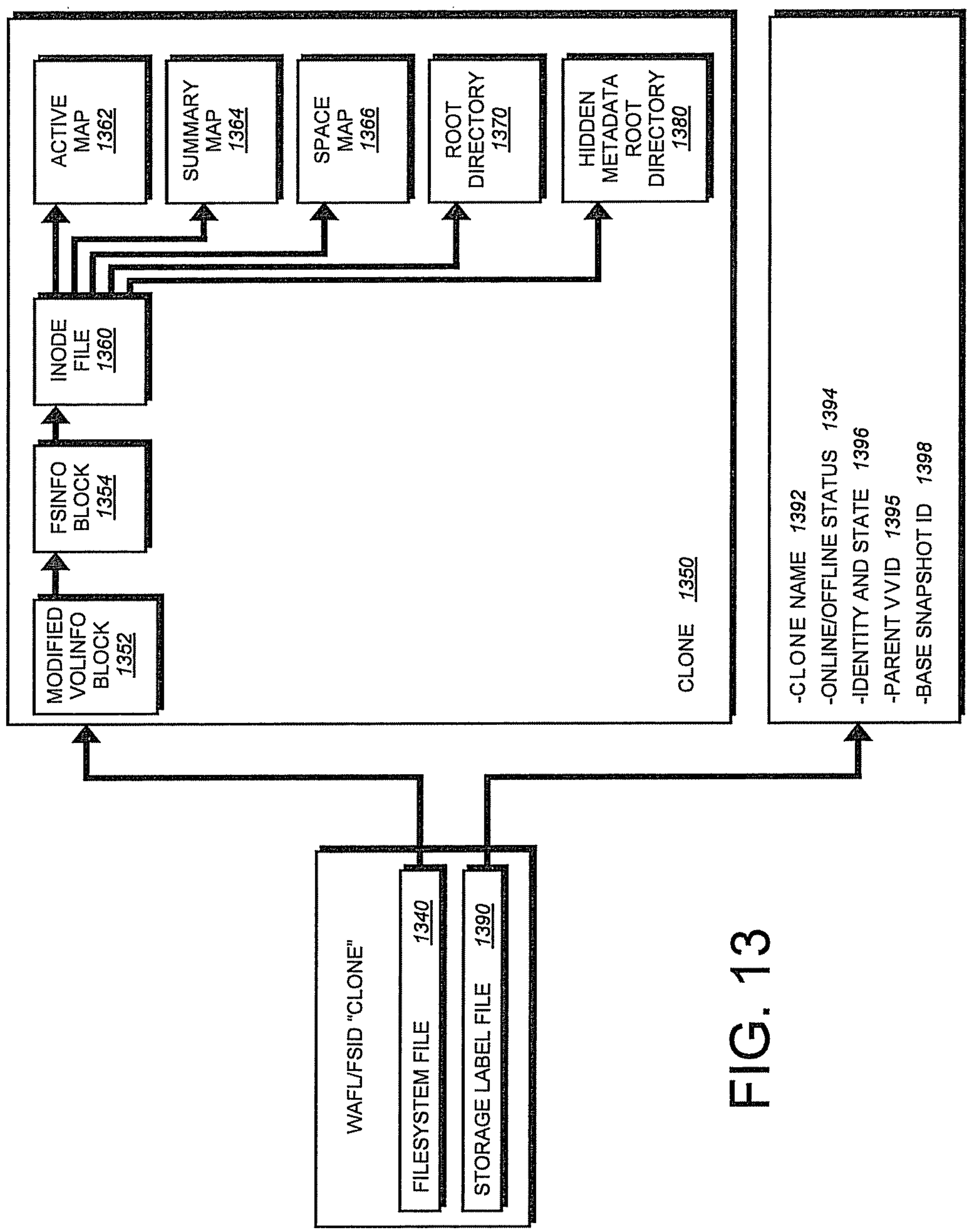

MODIFIED VOLINFO BLOCK 1352
FSINFO BLOCK 1354
INODE FILE 1360
ACTIVE MAP 1362
SUMMARY MAP 1364
SPACE MAP 1366
ROOT DIRECTORY 1370
HIDDEN METADATA ROOT DIRECTORY 1380
CLONE 1350
-CLONE NAME 1392
-ONLINE/OFFLINE STATUS 1394
-IDENTITY AND STATE 1396
-PARENT VVID 1395
-BASE SNAPSHOT ID 1398
WAFL/FSID "CLONE"
FILESYSTEM FILE 1340
STORAGE LABEL FILE 1390

FIG. 13

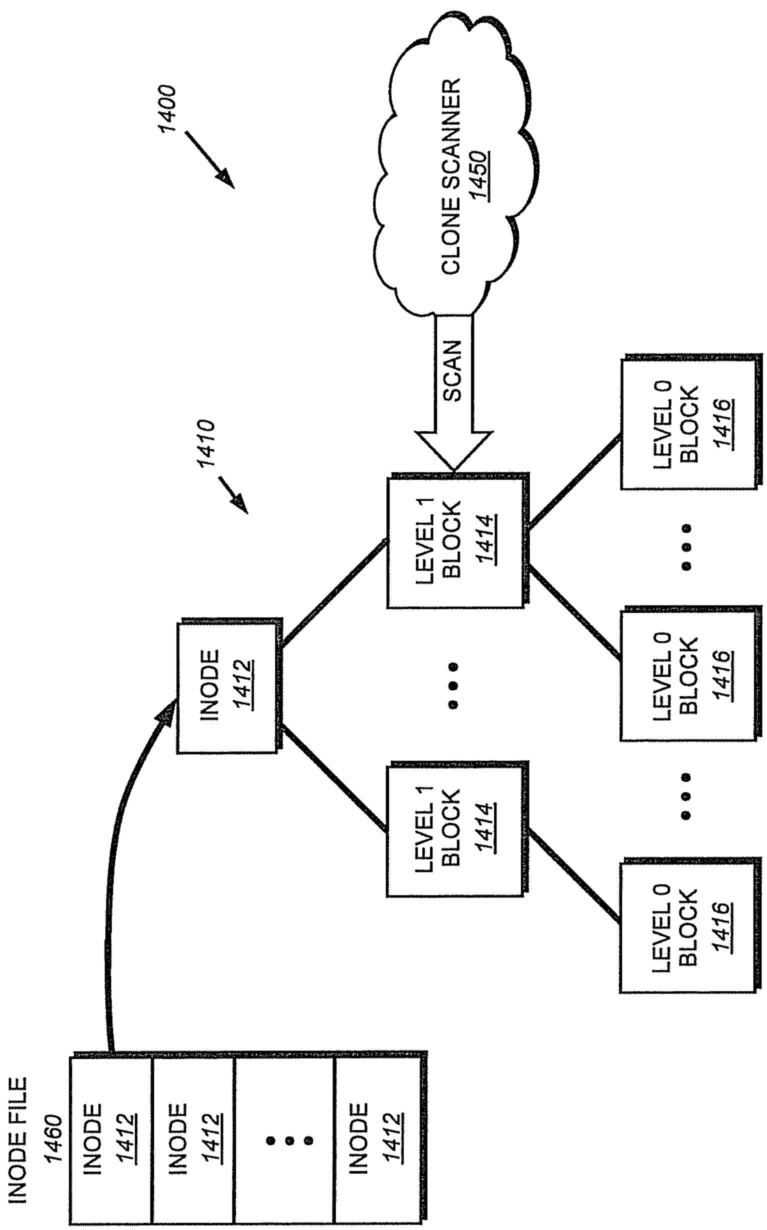

1400
CLONE SCANNER
1450
SCAN
1410
INODE
1412
LEVEL 1
BLOCK
1414
LEVEL 1
BLOCK
1414
LEVEL 0
BLOCK
1416
LEVEL 0
BLOCK
1416
LEVEL 0
BLOCK
1416
INODE FILE
1460
INODE
1412
INODE
1412
INODE
1412

FIG. 14

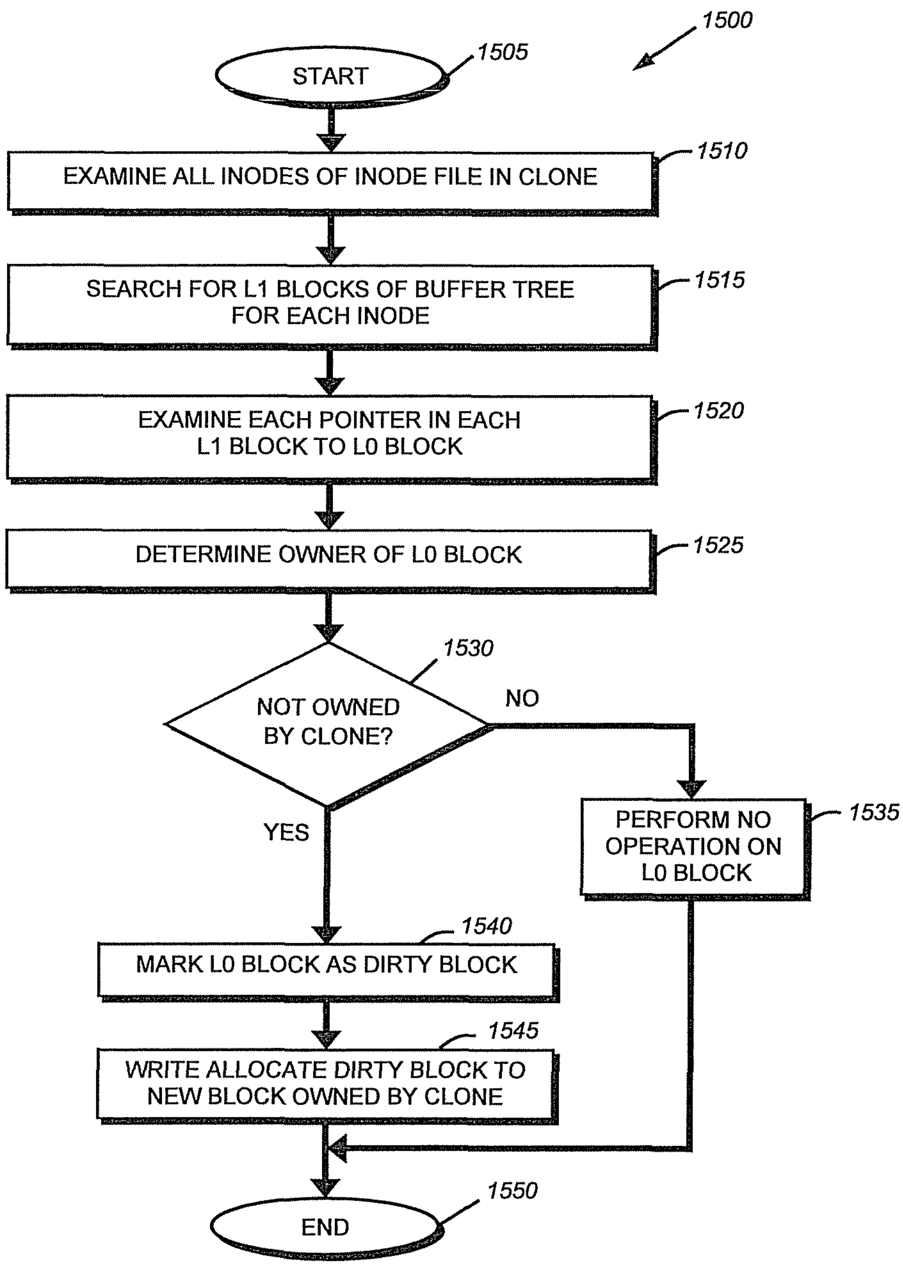

1500
START
1505
EXAMINE ALL INODES OF INODE FILE IN CLONE
1510
SEARCH FOR L1 BLOCKS OF BUFFER TREE FOR EACH INODE
1515
EXAMINE EACH POINTER IN EACH L1 BLOCK TO L0 BLOCK
1520
DETERMINE OWNER OF L0 BLOCK
1525
NOT OWNED BY CLONE?
1530
NO
YES
PERFORM NO OPERATION ON L0 BLOCK
1535
MARK L0 BLOCK AS DIRTY BLOCK
1540
WRITE ALLOCATE DIRTY BLOCK TO NEW BLOCK OWNED BY CLONE
1545
END
1550

FIG. 15

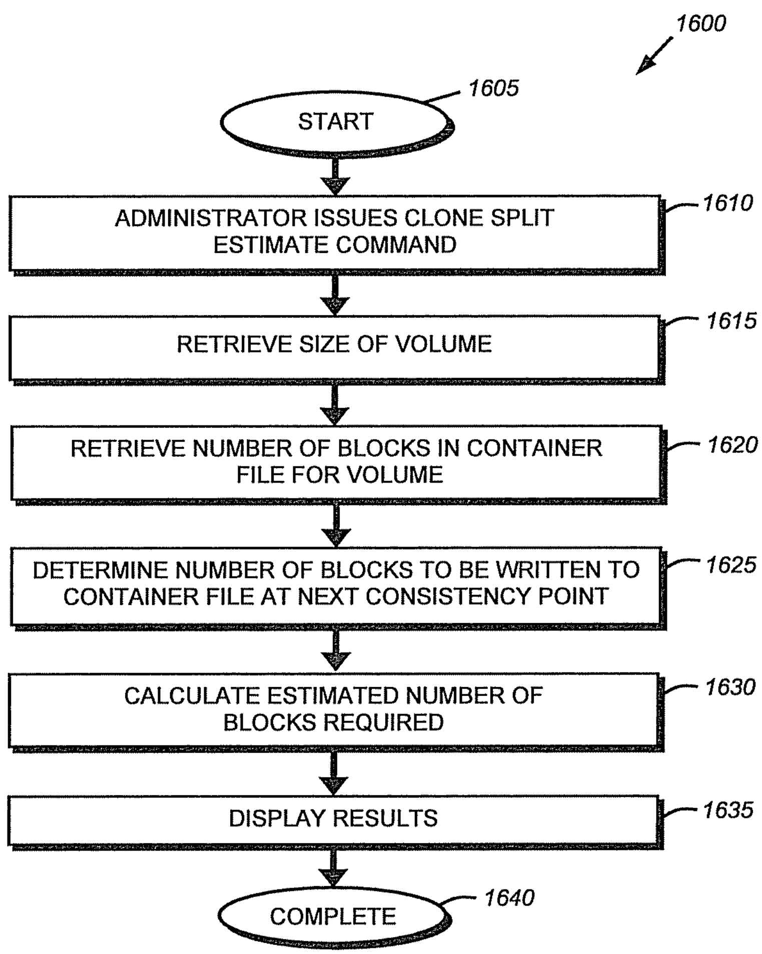

1600
1605
START
ADMINISTRATOR ISSUES CLONE SPLIT ESTIMATE COMMAND
1610
RETRIEVE SIZE OF VOLUME
1615
RETRIEVE NUMBER OF BLOCKS IN CONTAINER FILE FOR VOLUME
1620
DETERMINE NUMBER OF BLOCKS TO BE WRITTEN TO CONTAINER FILE AT NEXT CONSISTENCY POINT
1625
CALCULATE ESTIMATED NUMBER OF BLOCKS REQUIRED
1630
DISPLAY RESULTS
1635
COMPLETE
1640

FIG. 16

SYSTEM AND METHOD FOR EFFICIENTLY CALCULATING STORAGE REQUIRED TO SPLIT A CLONE VOLUME

CROSS-REFERENCE TO RELATED APPLICATIONS

The present invention is a continuation of U.S. patent application Ser. No. 11/082,098, entitled SYSTEM AND METHOD FOR EFFICIENTLY CALCULATING STORAGE REQUIRED TO SPLIT A CLONE VOLUME, by Robert L. Fair, filed on Mar. 16, 2005, which is now issued as U.S. Pat. No. 7,757,056 on Jul. 13, 2010, and which application is related to the following U.S. Patents:

U.S. Pat. No. 7,409,511, issued on Aug. 5, 2008, entitled CLONING TECHNIQUE FOR EFFICIENTLY CREATING A COPY OF A VOLUME IN A STORAGE SYSTEM, by John K. Edwards et al.; and

U.S. Pat. No. 7,334,094, issued on Feb. 19, 2008, entitled ONLINE CLONE VOLUME SPLITTING TECHNIQUE, by Robert L. Fair, the contents said patents are hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates to storage systems and, more specifically to efficiently calculating the storage required to split a clone volume from a parent volume.

BACKGROUND OF THE INVENTION

A storage system typically comprises one or more storage devices into which information may be entered, and from which information may be obtained, as desired. The storage system includes a storage operating system that functionally organizes the system by, inter alia, invoking storage operations in support of a storage service implemented by the system. The storage system may be implemented in accordance with a variety of storage architectures including, but not limited to, a network-attached storage environment, a storage area network and a disk assembly directly attached to a client or host computer. The storage devices are typically disk drives organized as a disk array, wherein the term "disk" commonly describes a self-contained rotating magnetic media storage device. The term disk in this context is synonymous with hard disk drive (HDD) or direct access storage device (DASD).

Storage of information on the disk array is preferably implemented as one or more storage "volumes" of physical disks, defining an overall logical arrangement of disk space. The disks within a volume are typically organized as one or more groups, wherein each group may be operated as a Redundant Array of Independent (or Inexpensive) Disks (RAID). Most RAID implementations enhance the reliability/integrity of data storage through the redundant writing of data "stripes" across a given number of physical disks in the RAID group, and the appropriate storing of redundant information (parity) with respect to the striped data. The physical disks of each RAID group may include disks configured to store striped data (i.e., data disks) and disks configured to store parity for the data (i.e., parity disks). The parity may thereafter be retrieved to enable recovery of data lost when a disk fails. The term "RAID" and its various implementations are well-known and disclosed in *A Case for Redundant Arrays of Inexpensive Disks* (*RAID*), by D. A. Patterson, G. A. Gibson and R. H. Katz, Proceedings of the International Conference on Management of Data (SIGMOD), June 1988.

The storage operating system of the storage system may implement a high-level module, such as a file system, to logically organize the information stored on the disks as a hierarchical structure of directories, files and blocks. For example, each "on-disk" file may be implemented as set of data structures, i.e., disk blocks, configured to store information, such as the actual data for the file. These data blocks are organized within a volume block number (vbn) space that is maintained by the file system. The file system may also assign each data block in the file a corresponding "file offset" or file block number (fbn). The file system typically assigns sequences of fbns on a per-file basis, whereas vbns are assigned over a larger volume address space. The file system organizes the data blocks within the vbn space as a "logical volume"; each logical volume may be, although is not necessarily, associated with its own file system. The file system typically consists of a contiguous range of vbns from zero to n, for a file system of size n−1 blocks.

A known type of file system is a write-anywhere file system that does not over-write data on disks. If a data block is retrieved (read) from disk into a memory of the storage system and "dirtied" (i.e., updated or modified) with new data, the data block is thereafter stored (written) to a new location on disk to optimize write performance. A write-anywhere file system may initially assume an optimal layout such that the data is substantially contiguously arranged on disks. The optimal disk layout results in efficient access operations, particularly for sequential read operations, directed to the disks. An example of a write-anywhere file system that is configured to operate on a storage system is the Write Anywhere File Layout (WAFL™) file system available from Network Appliance, Inc., Sunnyvale, Calif.

The storage operating system may further implement a storage module, such as a RAID system, that manages the storage and retrieval of the information to and from the disks in accordance with input/output (I/O) operations. The RAID system is also responsible for parity operations in the storage system. Note that the file system only "sees" the data disks within its vbn space; the parity disks are "hidden" from the file system and, thus, are only visible to the RAID system. The RAID system typically organizes the RAID groups into one large "physical" disk (i.e., a physical volume), such that the disk blocks are concatenated across all disks of all RAID groups. The logical volume maintained by the file system is then "disposed over" (spread over) the physical volume maintained by the RAID system.

A file system layout may apportion an underlying physical volume into one or more virtual volumes (vvols) of a storage system. An example of such a file system layout is described in U.S. Pat. No. 7,409,494 titled EXTENSION OF WRITE ANYWHERE FILE SYSTEM LAYOUT, by John K. Edwards et al. and assigned to Network Appliance, Inc. The underlying physical volume is an aggregate comprising one or more groups of disks, such as RAID groups, of the node. The aggregate has its own physical volume block number (pvbn) space and maintains metadata, such as block allocation structures, within that pvbn space. Each vvol has its own virtual volume block number (vvbn) space and maintains metadata, such as block allocation structures, within that vvbn space. Each vvol is a file system that is associated with a container file; the container file is a file in the aggregate that contains all blocks used by the vvol. Moreover, each vvol comprises data blocks and indirect blocks that contain block pointers that point at either other indirect blocks or data blocks.

File systems may incorporate a cloning technique that enables efficient and substantially instantaneous creation of a clone that is a writable copy of a "parent" virtual volume (vvol) in an aggregate of a storage system. An example of such a cloning technique is described in the above-incorporated U.S. Patent entitled CLONING TECHNIQUE FOR EFFICIENTLY CREATING A COPY OF A VOLUME IN A STORAGE SYSTEM. The clone is instantiated by, e.g., loading a file system associated with the new vvol onto the clone and bringing the clone "online", with the only blocks owned by the clone comprising its modified volinfo block. The file system executes on the clone as it would on a typical vvol, such as the parent vvol. In fact, the file system within the clone resembles the file system within a base snapshot, since they comprise substantially the same blocks on disk. The resulting clone is thus a "full-fledged" vvol, i.e., it can service storage (read and write) requests and has its own logical properties. As a result, the cloning technique enables the clone and parent vvol to share on-disk blocks of data in a zero-copy fashion, while also allowing for modifications.

As can be appreciated, the splitting of blocks shared between a clone and its parent may consume substantial disk storage space. Consequently an administrator must "manually" estimate the amount of storage space required to perform a clone splitting operation. In known implementations, the administrator may then initiate an online clone splitting operation and wait until the clone splitting operation substantially completes to determine whether it succeeded or failed due to a lack of disk space. This presents a noted disadvantage in that the time required to perform the clone splitting operation may be on the order of hours, thereby delaying results (i.e., success) of the operation for that length of time. An alternative, "brute force" technique for determining the amount of space required for a clone splitting operation is to determine, for each block in the clone, whether it is located in the clone's parent (or parent's parent, etc) or within the clone's container file. As a clone may be on the order of gigabytes or terabytes in size, the time required to make this determination is substantial.

SUMMARY OF THE INVENTION

The present invention overcomes the disadvantages of the prior art by providing a system and method for efficiently calculating an estimated amount of storage required to split a clone volume from its parent volume. The system and method is illustratively embodied as a command line interface (CLI) command, i.e., a clone split estimate command, executed by an estimation module of a storage system. Notably, the estimation module cooperates with a file system of the storage system to quickly access data structures containing information used to perform the storage calculation without the need to access each block of the clone and parent volumes.

In response to an administrator issuing the novel clone split estimate command, the estimation module interacts with the file system to retrieve the size (i.e., the number of blocks) of the clone volume. Illustratively, the clone volume size may be obtained by examining metadata of a file system information data structure associated with the volume. The estimation module then interacts with the file system to retrieve the number of blocks stored in a container file for the clone volume. Thereafter, the estimation module calculates the amount of storage required by subtracting the number of blocks in the container file from the number of blocks of the clone volume. The result of this calculation estimates the number of blocks stored in the parent volume of the clone (or parent's parent, etc.) that must be written during the clone split operation. This estimated number of blocks may be displayed to the administrator so that appropriate disk provisioning may occur before the initiation of a clone split operation.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and further advantages of the invention may be better understood by referring to the following description in conjunction with the accompanying drawings in which like reference numerals indicate identical or functionally similar elements:

FIG. **1** is a schematic block diagram of an environment including a storage system that may be advantageously used with the present invention;

FIG. **2** is a schematic block diagram of a storage operating system that may be advantageously used with the present invention;

FIG. **3** is a schematic block diagram of an exemplary file system mode structure;

FIG. **4** is a schematic block diagram of the exemplary file system mode structure of FIG. **3** including a persistent consistency point image (PCPI) mode;

FIG. **5** is a schematic block diagram of an exemplary file system mode structure of FIG. **4** after a data block has been rewritten;

FIG. **6** is a schematic block diagram of an mode that may be advantageously used with the present invention;

FIG. **7** is a schematic block diagram of a buffer tree of a file that may be advantageously used with the present invention;

FIG. **8** is a schematic block diagram of an embodiment of an aggregate that may be advantageously used with the present invention;

FIG. **9** is a schematic block diagram of an on-disk representation of an aggregate;

FIG. **10** is a schematic block diagram of a container file that may be advantageously used with the present invention;

FIG. **11** is a schematic block diagram of an owner map that may be advantageously used with the present invention;

FIG. **12** is a schematic block diagram illustrating an embodiment of an aggregate that may be advantageously used with the present invention;

FIG. **13** is a schematic block diagram of an on-disk representation of a clone that may be advantageously used with the present invention;

FIG. **14** is a schematic block diagram illustrating a clone splitting technique in accordance with the present invention;

FIG. **15** is a flowchart illustrating a shared block splitting procedure in accordance with the cloning splitting technique; and

FIG. **16** is a flowchart detailing the steps of a procedure for calculating the amount of storage required to split a clone from its parent in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

A. Storage System

FIG. **1** is a schematic block diagram of an environment **100** including a storage system **120** that may be advantageously used with the present invention. The storage system is a computer that provides storage service relating to the organization of information on storage devices, such as disks **130** of a disk array **160**. The storage system **120** comprises a processor **122**, a memory **124**, a network adapter **126** and a storage adapter **128** interconnected by a system bus **125**. The storage system **120** also includes a storage operating system **200** that preferably implements a high-level module, such as a file system, to logically organize the information as a hierarchical structure of directories, files and special types of files called virtual disks (hereinafter "blocks") on the disks.

In the illustrative embodiment, the memory **124** comprises storage locations that are addressable by the processor and adapters for storing software program code. A portion of the memory may be further organized as a "buffer cache" **170** for storing data structures associated with the present invention. The processor and adapters may, in turn, comprise processing elements and/or logic circuitry configured to execute the software code and manipulate the data structures. Storage operating system **200**, portions of which are typically resident in memory and executed by the processing elements, functionally organizes the system **120** by, inter alia, invoking storage operations executed by the storage system. It will be apparent to those skilled in the art that other processing and memory means, including various computer readable media, may be used for storing and executing program instructions pertaining to the inventive technique described herein.

The network adapter **126** comprises the mechanical, electrical and signaling circuitry needed to connect the storage system **120** to a client **110** over a computer network **140**, which may comprise a point-to-point connection or a shared medium, such as a local area network. Illustratively, the computer network **140** may be embodied as an Ethernet network or a Fibre Channel (FC) network. The client **110** may communicate with the storage system over network **140** by exchanging discrete frames or packets of data according to pre-defined protocols, such as the Transmission Control Protocol/Internet Protocol (TCP/IP).

The client **110** may be a general-purpose computer configured to execute applications **112**. Moreover, the client **110** may interact with the storage system **120** in accordance with a client/server model of information delivery. That is, the client may request the services of the storage system, and the system may return the results of the services requested by the client, by exchanging packets **150** over the network **140**. The clients may issue packets including file-based access protocols, such as the Common Internet File System (CIFS) protocol or Network File System (NFS) protocol, over TCP/IP when accessing information in the form of files and directories. Alternatively, the client may issue packets including block-based access protocols, such as the Small Computer Systems Interface (SCSI) protocol encapsulated over TCP (iSCSI) and SCSI encapsulated over Fibre Channel (FCP), when accessing information in the form of blocks.

The storage adapter **128** cooperates with the storage operating system **200** executing on the system **120** to access information requested by a user (or client). The information may be stored on any type of attached array of writable storage device media such as video tape, optical, DVD, magnetic tape, bubble memory, electronic random access memory, micro-electro mechanical and any other similar media adapted to store information, including data and parity information. However, as illustratively described herein, the information is preferably stored on the disks **130**, such as HDD and/or DASD, of array **160**. The storage adapter includes input/output (I/O) interface circuitry that couples to the disks over an I/O interconnect arrangement, such as a conventional high-performance, FC serial link topology.

Storage of information on array **160** is preferably implemented as one or more storage "volumes" that comprise a collection of physical storage disks **130** cooperating to define an overall logical arrangement of volume block number (vbn) space on the volume(s). Each logical volume is generally, although not necessarily, associated with its own file system. The disks within a logical volume/file system are typically organized as one or more groups, wherein each group may be operated as a Redundant Array of Independent (or Inexpensive) Disks (RAID). Most RAID implementations, such as a RAID-4 level implementation, enhance the reliability/integrity of data storage through the redundant writing of data "stripes" across a given number of physical disks in the RAID group, and the appropriate storing of parity information with respect to the striped data. An illustrative example of a RAID implementation is a RAID-4 level implementation, although it should be understood that other types and levels of RAID implementations may be used in accordance with the inventive principles described herein.

B. Storage Operating System

To facilitate access to the disks **130**, the storage operating system **200** implements a write-anywhere file system that cooperates with virtualization modules to "virtualize" the storage space provided by disks **130**. The file system logically organizes the information as a hierarchical structure of named directories and files on the disks. Each "on-disk" file may be implemented as set of disk blocks configured to store information, such as data, whereas the directory may be implemented as a specially formatted file in which names and links to other files and directories are stored. The virtualization modules allow the file system to further logically organize information as a hierarchical structure of blocks on the disks that are exported as named logical unit numbers (luns).

In the illustrative embodiment, the storage operating system is preferably the NetApp® Data ONTAP™ operating system available from Network Appliance, Inc., Sunnyvale, Calif. that implements a Write Anywhere File Layout (WAFL™) file system. However, it is expressly contemplated that any appropriate storage operating system may be enhanced for use in accordance with the inventive principles described herein. As such, where the term "WAFL" is employed, it should be taken broadly to refer to any storage operating system that is otherwise adaptable to the teachings of this invention.

FIG. **2** is a schematic block diagram of the storage operating system **200** that may be advantageously used with the present invention. The storage operating system comprises a series of software layers organized to form an integrated network protocol stack or, more generally, a multi-protocol engine that provides data paths for clients to access information stored on the storage system using block and file access protocols. The protocol stack includes a media access layer **210** of network drivers (e.g., gigabit Ethernet drivers) that interfaces to network protocol layers, such as the IP layer **212** and its supporting transport mechanisms, the TCP layer **214** and the User Datagram Protocol (UDP) layer **216**. A file system protocol layer provides multi-protocol file access and, to that end, includes support for the Direct Access File System (DAFS) protocol **218**, the NFS protocol **220**, the CIFS protocol **222** and the Hypertext Transfer Protocol (HTTP) protocol **224**. A VI layer **226** implements the VI architecture to provide direct access transport (DAT) capabilities, such as RDMA, as required by the DAFS protocol **218**.

An iSCSI driver layer **228** provides block protocol access over the TCP/IP network protocol layers, while a FC driver layer **230** receives and transmits block access requests and responses to and from the storage system. The FC and iSCSI drivers provide FC-specific and iSCSI-specific access control to the blocks and, thus, manage exports of luns to either iSCSI or FCP or, alternatively, to both iSCSI and FCP when accessing the blocks on the storage system. In addition, the storage operating system includes a storage module embodied as a RAID system **240** that manages the storage and retrieval of information to and from the volumes/disks in accordance with I/O operations, and a disk driver system **250** that implements a disk access protocol such as, e.g., the SCSI protocol.

Bridging the disk software layers with the integrated network protocol stack layers is a virtualization system that is implemented by a file system **280** interacting with virtualization modules illustratively embodied as, e.g., vdisk module **260** and SCSI target module **270**. The vdisk module **260** is layered on the file system **280** to enable access by administrative interfaces, such as a user interface (UI) **275**, in response to a user (system administrator) issuing commands to the storage system. The SCSI target module **270** is disposed between the FC and iSCSI drivers **228**, **230** and the file system **280** to provide a translation layer of the virtualization system between the block (lun) space and the file system space, where luns are represented as blocks. The UI **275** is disposed over the storage operating system in a manner that enables administrative or user access to the various layers and systems. The UI includes a novel estimation module **295** that enables an administrator to efficiently estimate the amount of storage required to split a clone volume from its patent volume in accordance with an embodiment of the present invention. To that end, the estimate module **295** illustratively implements a novel clone split estimate command, described further below.

The file system is illustratively a message-based system that provides logical volume management capabilities for use in access to the information stored on the storage devices, such as disks. That is, in addition to providing file system semantics, the file system **280** provides functions normally associated with a volume manager. These functions include (i) aggregation of the disks, (ii) aggregation of storage bandwidth of the disks, and (iii) reliability guarantees, such as mirroring and/or parity (RAID). The file system **280** illustratively implements the WAFL file system (hereinafter generally the "write-anywhere file system") having an on-disk format representation that is block-based using, e.g., 4 kilobyte (kB) blocks and using index nodes ("modes") to identify files and file attributes (such as creation time, access permissions, size and block location). The file system uses files to store metadata describing the layout of its file system; these metadata files include, among others, an mode file. A file handle, i.e., an identifier that includes an mode number, is used to retrieve an mode from disk.

Broadly stated, all modes of the write-anywhere file system are organized into the mode file. A file system (FS) info block specifies the layout of information in the file system and includes an mode of a file that includes all other modes of the file system. Each logical volume (file system) has an FS info block that is preferably stored at a fixed location within, e.g., a RAID group. The mode of the mode file may directly reference (point to) blocks of the mode file or may reference indirect blocks of the mode file that, in turn, reference direct blocks of the mode file. Within each direct block of the mode file are embedded modes, each of which may reference indirect blocks that, in turn, reference data blocks of a file.

Operationally, a request from the client **110** is forwarded as a packet **150** over the computer network **140** and onto the storage system **120** where it is received at the network adapter **126**. A network driver (of layer **210** or layer **230**) processes the packet and, if appropriate, passes it on to a network protocol and file access layer for additional processing prior to forwarding to the write-anywhere file system **280**. Here, the file system generates operations to load (retrieve) the requested data from disk **130** if it is not resident "in core", i.e., in the buffer cache **170**. If the information is not in the cache, the file system **280** indexes into the mode file using the mode number to access an appropriate entry and retrieve a logical vbn. The file system then passes a message structure including the logical vbn to the RAID system **240**; the logical vbn is mapped to a disk identifier and disk block number (disk,dbn) and sent to an appropriate driver (e.g., SCSI) of the disk driver system **250**. The disk driver accesses the dbn from the specified disk **130** and loads the requested data block(s) in buffer cache **170** for processing by the storage system. Upon completion of the request, the storage system (and operating system) returns a reply to the client **110** over the network **140**.

It should be noted that the software "path" through the storage operating system layers described above needed to perform data storage access for the client request received at the storage system may alternatively be implemented in hardware. That is, in an alternate embodiment of the invention, a storage access request data path may be implemented as logic circuitry embodied within a field programmable gate array (FPGA) or an application specific integrated circuit (ASIC). This type of hardware implementation increases the performance of the storage service provided by storage system **120** in response to a request issued by client **110**. Moreover, in another alternate embodiment of the invention, the processing elements of adapters **126**, **128** may be configured to offload some or all of the packet processing and storage access operations, respectively, from processor **122**, to thereby increase the performance of the storage service provided by the system. It is expressly contemplated that the various processes, architectures and procedures described herein can be implemented in hardware, firmware or software.

As used herein, the term "storage operating system" generally refers to the computer-executable code operable to perform a storage function in a storage system, e.g., that manages data access and may, in the case of a file server, implement file system semantics. In this sense, the ONTAP software is an example of such a storage operating system implemented as a microkernel and including the WAFL layer to implement the WAFL file system semantics and manage data access. The storage operating system can also be implemented as an application program operating over a general-purpose operating system, such as UNIX® or Windows NT®, or as a general-purpose operating system with configurable functionality, which is configured for storage applications as described herein.

In addition, it will be understood to those skilled in the art that the inventive technique described herein may apply to any type of special-purpose (e.g., file server, filer or multi-protocol storage appliance) or general-purpose computer, including a standalone computer or portion thereof, embodied as or including a storage system **120**. An example of a multi-protocol storage appliance that may be advantageously used with the present invention is described in U.S. patent application Ser. No. 10/215,917 titled, MULTI-PROTOCOL STORAGE APPLIANCE THAT PROVIDES INTEGRATED SUPPORT FOR FILE AND BLOCK ACCESS PROTOCOLS, filed on Aug. 8, 2002 by Brian Pawlowski et al., which was published on Feb. 12, 2004 as Patent Publication No. 2004/0030668 A1. Moreover, the teachings of this invention can be adapted to a variety of storage system architectures including, but not limited to, a network-attached storage environment, a storage area network and disk assembly directly-attached to a client or host computer. The term "storage system" should therefore be taken broadly to include such arrangements in addition to any subsystems configured to perform a storage function and associated with other equipment or systems.

C. Persistent Consistency Point Images (PCPIs)

The write-anywhere file system further supports multiple persistent consistency point images (PCPIs) that are generally created on a regular schedule. A persistent consistency point image (PCPI) is a space conservative, point-in-time read-only image of data accessible by name that provides a consistent image of that data (such as a storage system) at some previous time. More particularly, a PCPI is a point-in-time representation of a storage element, such as an active file system, file or database, stored on a storage device (e.g., on disk) or other persistent memory and having a name or other identifier that distinguishes it from other PCPIs taken at other points in time. In the case of the WAFL file system, a PCPI is always an active file system image that contains complete information about the file system, including all metadata. A PCPI can also include other information (metadata) about the active file system at the particular point in time for which the image is taken. The terms "PCPI" and "snapshot" may be used interchangeably through out this patent without derogation of Network Appliance's trademark rights. Each PCPI refers to a copy of the file system that diverges from the active file system over time as the active file system is modified. In the case of the WAFL file system, the active file system diverges from the PCPIs since the PCPIs stay in place as the active file system is written to new disk locations. Each PCPI is a restorable version of the storage element (e.g., the active file system) created at a predetermined point in time and, as noted, is "read-only" accessible and "space-conservative". Space conservative denotes that common parts of the storage element in multiple PCPIs share the same file system blocks. Only the differences among these various PCPIs require extra storage blocks. The multiple PCPIs of a storage element are not independent copies, each consuming disk space; therefore, creation of a PCPI on the file system is instantaneous, since no entity data needs to be copied. Read-only accessibility denotes that a PCPI cannot be modified because it is closely coupled to a single writable image in the active file system. The closely coupled association between a file in the active file system and the same file in a PCPI obviates the use of multiple "same" files. In the example of a WAFL file system, PCPIs are described in *TR*3002 *File System Design for a NFS File Server Appliance* by David Hitz et al., published by Network Appliance, Inc. and in U.S. Pat. No. 5,819,292 entitled METHOD FOR MAINTAINING CONSISTENT STATES OF A FILE SYSTEM AND FOR CREATING USER-ACCESSIBLE READ-ONLY COPIES OF A FILE SYSTEM, by David Hitz et al., each of which is hereby incorporated by reference as though full set forth herein.

Broadly stated, a PCPI is stored on-disk along with the active file system, and is called into the memory of the storage system as requested by the storage operating system. The on-disk organization of the PCPI and the active file system can be understood from the following description of an exemplary file system mode structure **300** shown in FIG. **3**. The mode for an mode file **305** contains information describing the mode file associated with a file system. In this exemplary file system mode structure, the mode for the mode file **305** contains a pointer that references (points to) an mode file indirect block **310**. The mode file indirect block **310** contains a set of pointers that reference mode file blocks, each of which contains an array of modes **317**, which in turn contain pointers to indirect blocks **319**. The indirect blocks **319** include pointers to file data blocks **320**A, **320**B and **320**C. Each of the file data blocks **320**(A-C) is capable of storing, e.g., 4 kilobytes (kB) of data.

When the file system generates a PCPI of its active file system, a PCPI mode is generated as shown in FIG. **4**. The PCPI mode **405** is, in essence, a duplicate copy of the mode for the mode file **305** of the file system mode structure **300** that shares common parts, such as modes and blocks, with the active file system. For example, the exemplary file system mode structure **400** includes the mode file indirect blocks **310**, modes **317**, indirect blocks **319** and file data blocks **320**A-C as in FIG. **3**. When a user modifies a file data block, the file system writes the new data block to disk and changes the active file system to point to the newly created block. FIG. **5** shows an exemplary file system mode structure **500** after a file data block has been modified. In this example, file data block **320**C is modified to file data block **320**C'. As a result, the contents of the modified file data block are written to a new location on disk as a function of the exemplary file system. Because of this new location, the indirect block **319** must be rewritten. Due to this changed indirect block **319**, the mode **317** must be rewritten. Similarly, the mode file indirect block **310** and the mode for the mode file **305** must be rewritten.

Thus, after a file data block has been modified, the PCPI mode **405** contains a pointer to the original mode file indirect block **110** which, in turn, contains pointers through the mode **117** and indirect block **119** to the original file data blocks **120**A, **120**B and **120**C. The newly written indirect block **319** also includes pointers to unmodified file data blocks **120**A and **120**B. That is, the unmodified data blocks in the file of the active file system are shared with corresponding data blocks in the snapshot file, with only those blocks that have been modified in the active file system being different than those of the snapshot file.

However, the indirect block **319** further contains a pointer to the modified file data block **120**C' representing the new arrangement of the active file system. A new mode for the mode file **305** is established representing the new structure **300**. Note that metadata (not shown) stored in any snapshotted blocks (e.g., **405**, **110**, and **120**C) protects these blocks from being recycled or overwritten until they are released from all snapshots. Thus, while the active file system mode for the mode file **305** points to new blocks **310**, **317**, **319**, **120**A, **120**B and **120**C', the old blocks **405**, **110** and **120**C are retained until the snapshot is fully released.

PCPIs provide a versatile feature that is essential for data recovery operations, such as backup and recovery of storage elements. However, since PCPIs are read-only accessible and their contents cannot be modified, their use may be somewhat limited, particularly for operating systems and applications that do not have a notion of a read-only data store (a read-only file system) and that expect to write metadata at any time that the file system is accessible. When a storage element that is held in a PCPI is exported to a client and contains the data for such a problematic file system, an issue arises in that the client attempts to write data to the read-only image. This is a fundamental issue in the design of a reliable system for backups. In general, once a backup image is made (via a mechanism like a PCPI), that image should be inviolate. Modifying a PCPI ("backup") image could have serious consequences in that the data of the PCPI may no longer be a "point-in-time" copy and a consistent image of the storage element data may no longer be available for subsequent recovery operations.

This limitation may be overcome by creating a substantially instantaneous copy of a volume in accordance with a cloning technique as described in the above-incorporated U.S. Pat. No. 7,409,511 entitled CLONING TECHNIQUE FOR EFFICIENTLY CREATING A COPY OF A VOLUME IN A STORAGE SYSTEM. The cloning technique enables efficient creation of a clone volume ("clone") of a "parent" virtual volume (vvol) described further below, based on a common PCPI. The resulting clone is a "full-fledged" vvol, i.e., it can service storage (read and write) requests and has its own logical properties, such as snapshot operation functionality. Broadly stated, the clone initially shares disk storage with its parent vvol. As write operations are directed to the clone, the disk storage diverges with the clone acquiring its own storage on a block-by-block manner. However, the clone remains tied to the parent vvol through the common base PCPI. The base PCPI is "locked" in the parent to prevent the common blocks from being changed by write operations to the parent vvol. As data is written to the clone, new blocks are allocated in a container file of the clone.

D. File System Data Structures

In the illustrative embodiment, a file is represented in the write-anywhere file system as an mode data structure adapted for storage on the disks **130**. FIG. **6** is a schematic block diagram of an mode **600**, which preferably includes a metadata section **610** and a data section **650**. The information stored in the metadata section **610** of each mode **600** describes the file and, as such, includes the type (e.g., regular, directory, virtual disk) **612** of file, the size **614** of the file, time stamps (e.g., access and/or modification) **616** for the file and ownership, i.e., user identifier (UID **618**) and group ID (GID **620**), of the file. The contents of the data section **650** of each mode, however, may be interpreted differently depending upon the type of file (mode) defined within the type field **612**. For example, the data section **650** of a directory mode contains metadata controlled by the file system, whereas the data section of a regular mode contains file system data. In this latter case, the data section **650** includes a representation of the data associated with the file.

Specifically, the data section **650** of a regular on-disk mode may include file system data or pointers, the latter referencing 4 kB data blocks on disk used to store the file system data. Each pointer is preferably a logical vbn to facilitate efficiency among the file system and the RAID system **240** when accessing the data on disks. Given the restricted size (e.g., 128 bytes) of the mode, file system data having a size that is less than or equal to 64 bytes is represented, in its entirety, within the data section of that mode. However, if the file system data is greater than 64 bytes but less than or equal to 64 kB, then the data section of the mode (e.g., a first level mode) comprises up to 16 pointers, each of which references a 4 kB block of data on the disk.

Moreover, if the size of the data is greater than 64 kB but less than or equal to 64 megabytes (MB), then each pointer in the data section **650** of the mode (e.g., a second level mode) references an indirect block (e.g., a first level block) that contains 1024 pointers, each of which references a 4 kB data block on disk. For file system data having a size greater than 64 MB, each pointer in the data section **650** of the mode (e.g., a third level mode) references a double-indirect block (e.g., a second level block) that contains 1024 pointers, each referencing an indirect (e.g., a first level) block. The indirect block, in turn, that contains 1024 pointers, each of which references a 4 kB data block on disk. When accessing a file, each block of the file may be loaded from disk **130** into the buffer cache **170**.

When an on-disk mode (or block) is loaded from disk **130** into buffer cache **170**, its corresponding in core structure embeds the on-disk structure. For example, the dotted line surrounding the mode **600** indicates the in-core representation of the on-disk mode structure. The in-core structure is a block of memory that stores the on-disk structure plus additional information needed to manage data in the memory (but not on disk). The additional information may include, e.g., a "dirty" bit **660**. After data in the mode (or block) is updated/modified as instructed by, e.g., a write operation, the modified data is marked "dirty" using the dirty bit **660** so that the mode (block) can be subsequently "flushed" (stored) to disk. The in-core and on-disk format structures of the WAFL file system, including the modes and mode file, are disclosed and described in the previously incorporated U.S. Pat. No. 5,819,292 titled METHOD FOR MAINTAINING CONSISTENT STATES OF A FILE SYSTEM AND FOR CREATING USER-ACCESSIBLE READ-ONLY COPIES OF A FILE SYSTEM by David Hitz, et al., issued on Oct. 6, 1998.

FIG. **7** is a schematic block diagram of a buffer tree of a file that may be advantageously used with the present invention. The buffer tree is an internal representation of blocks for a file (e.g., file **700**) loaded into the buffer cache **170** and maintained by the write-anywhere file system **280**. A root (top-level) mode **702**, such as an embedded mode, references indirect (e.g., level 1) blocks **704**. The indirect blocks (and mode) contain pointers **705** that ultimately reference data blocks **706** used to store the actual data of file. That is, the data of file **700** are contained in data blocks and the locations of these blocks are stored in the indirect blocks of the file. Each level 1 indirect block **704** may contain pointers to as many as 1024 data blocks. According to the "write anywhere" nature of the file system, these blocks may be located anywhere on the disks **130**.

The present invention employs a cloning technique that, as noted, enables efficient and substantially instantaneous creation of a clone that is a copy of a parent vvol in an aggregate of a storage system. The aggregate is a physical volume comprising one or more groups of disks, such as RAID groups, underlying one or more vvols of the storage system. The aggregate has its own physical volume block number (pvbn) space and maintains metadata, such as block allocation bitmap structures, within that pvbn space. The parent vvol may be a typical vvol that, like any vvol, has its own virtual volume block number (vvbn) space and maintains metadata, such as block allocation bitmap structures, within that vvbn space.

Illustratively, pvbns are used as block pointers within buffer trees of files (such as file **700**) stored in a vvol. This illustrative "hybrid" vvol embodiment involves the insertion of only the pvbn in the parent indirect block (e.g., mode or indirect block). Use of pvbns avoids latency associated with translations from vvbns-to-pvbns, e.g., when servicing file system (such as NFS, CIFS) requests. On a read path of a logical volume, a "logical" volume (vol) info block has one or more pointers that reference one or more fsinfo blocks, each of which, in turn, "points to" an Mode file and its corresponding Mode buffer tree. The read path on a vvol is generally the same, following pvbns (instead of vvbns) to find appropriate locations of blocks; in this context, the read path (and corresponding read performance) of a vvol is substantially similar to that of a physical volume. Translation from pvbn-to-disk, dbn occurs at the file system/RAID system boundary of the storage operating system **200**.

In an alternate "dual vbn hybrid" vvol embodiment, both the pvbn and vvbn are inserted in the parent indirect (e.g., level 1) blocks in the buffer tree of a file, such as file **700**.

Here, the use of pvbns as block pointers in the indirect blocks provides efficiencies in the read paths, while the use of vvbn block pointers provide efficient access to required metadata. That is, when freeing a block of a file, the parent indirect block in the file contains readily available vvbn block pointers, which avoids the latency associated with accessing an owner map (described herein) to perform pvbn-to-vvbn translations; yet, on the read path, the pvbn is available. A disadvantage of this dual vbn variant is the increased size of indirection data (metadata) stored in each file.

E. Aggregate

FIG. **8** is a schematic block diagram of an embodiment of an aggregate **800** that may be advantageously used with the present invention. Luns (blocks) **802**, directories **804**, qtrees **806** and files **808** may be contained within vvols **810** that, in turn, are contained within the aggregate **800**. The aggregate **800** is illustratively layered on top of the RAID system, which is represented by at least one RAID plex **850** (depending upon whether the storage configuration is mirrored), wherein each plex **850** comprises at least one RAID group **860**. Each RAID group further comprises a plurality of disks **830**, e.g., one or more data (D) disks and at least one (P) parity disk.

Whereas the aggregate **800** is analogous to a physical volume of a conventional storage system, a vvol is analogous to a file within that physical volume. That is, the aggregate **800** may include one or more files, wherein each file contains a vvol **810** and wherein the sum of the storage space consumed by the vvols is physically smaller than (or equal to) the size of the overall physical volume. The aggregate utilizes a "physical" pvbn space that defines a storage space of blocks provided by the disks of the physical volume, while each embedded vvol (within a file) utilizes a "logical" vvbn space to organize those blocks, e.g., as files. Each vvbn space is an independent set of numbers that corresponds to locations within the file, which locations are then translated to dbns on disks. Since the vvol **810** is also a logical volume, it has its own block allocation structures (e.g., active, space and summary maps) in its vvbn space.

FIG. **9** is a schematic block diagram of an on-disk representation of an aggregate **900**. The storage operating system **200**, e.g., the RAID system **240**, assembles a physical volume of pvbns to create the aggregate **900**, with pvbns **1** and **2** comprising a "physical" volinfo block **902** for the aggregate. Broadly stated, a volinfo block stores volume-level information, as well as provides support for large numbers of snapshots. To that end, the volinfo block **902** contains block pointers to fsinfo blocks **904**, each of which may represent a snapshot of the aggregate. Each fsinfo block **904** includes a block pointer to an mode file **906** that contains modes of a plurality of files, including an owner map **1100**, an active map **912**, a summary map **914** and a space map **916**, as well as other special metadata files. The mode file **906** further includes a root directory **920** and a "hidden" metadata root directory **930**, the latter of which includes a namespace having files related to a vvol in which users cannot "see" the files. The hidden metadata root directory also includes a WAFL/fsid/directory structure, as described herein, which contains a filesystem file **940** and storage label file **990**. Note that root directory **920** in the aggregate is empty; all files related to the aggregate are organized within the hidden metadata root directory **930**.

The filesystem file **940** includes block pointers that reference various file systems embodied as vvols **950**. The aggregate **900** maintains these vvols **950** at special reserved mode numbers. Each vvol **950** also has special reserved mode numbers within its vvol space that are used for, among other things, the block allocation bitmap structures. As noted, the block allocation bitmap structures, e.g., active map **962**, summary map **964** and space map **966**, are located in each vvol.

Specifically, each vvol **950** has the same mode file structure/content as the aggregate, with the exception that there is no owner map and no WAFL/fsid/filesystem file, storage label file directory structure in a hidden metadata root directory **980**. To that end, each vvol **950** has a volinfo block **952** that points to one or more fsinfo blocks **954**, each of which may represent a PCPI of the vvol. Each fsinfo block **954** includes metadata relating to the vvol, including the size of the vvol. Each fsinfo block, in turn, points to an mode file **960** that, as noted, has the same mode structure/content as the aggregate with the exceptions noted above. Each vvol **950** has its own mode file **960** and distinct mode space with corresponding mode numbers, as well as its own root (fsid) directory **970** and subdirectories of files that can be exported separately from other vvols.

The storage label file **990** contained within the hidden metadata root directory **930** of the aggregate is a small file that functions as an analog to a conventional raid label. A raid label includes "physical" information about the storage system, such as the volume name; that information is loaded into the storage label file **990**. Illustratively, the storage label file **990** includes the name **992** of the associated vvol **950**, the online/offline status **994** of the vvol, and other identity and state information **996** of the associated vvol (whether it is in the process of being created or destroyed).

A container file is a file in the aggregate that contains all blocks used by a vvol. The container file is an internal (to the aggregate) feature that supports a vvol; illustratively, there is one container file per vvol. The container file is a hidden file (not accessible to a user) in the aggregate that holds every block in use by the vvol. As noted, the aggregate includes an illustrative hidden metadata root directory that contains subdirectories of vvols:

WAFL/Fsid/Filesystem File, Storage Label File

Specifically, a "physical" file system (WAFL) directory includes a subdirectory for each vvol in the aggregate, with the name of subdirectory being a file system identifier (fsid) of the vvol. Each fsid subdirectory (vvol) has at least two files, the filesystem file **940** and the storage label file **990**. The filesystem file is a large sparse file that contains all blocks owned by a vvol and, as such, is referred to as the container file for the vvol. FIG. **10** is a schematic block diagram of a container file **1000** (buffer tree) that is assigned a new type and has an mode **1002** that is assigned an mode number equal to a virtual volume id (vvid) of the vvol, e.g., container file **1000** has an mode number **113**. The container file is essentially one large virtual disk and, since it contains all blocks owned by its vvol, a block with vvbn X in the vvol can be found at fbn X in the container file. For example, vvbn **2000** in a vvol can be found at fbn **2000** in its container file **1000**. Since each vvol has its own distinct vvbn space, another container file may have fbn **2000** that is different from fbn **2000** in the illustrative container file **1000**.

Assume that a level 0 block **1006** of the container file **1000** has an fbn **2000** and an indirect (level 1) block **1004** of the level 0 block **1006** has a block pointer referencing the level 0 block, wherein the block pointer has a pvbn **20**. Thus, location fbn **2000** of the container file **1000** is pvbn **20** (on disk). Notably, the block numbers are maintained at the first indirect level (level 1) of the container file **1000**; e.g., to locate block **2000** in the container file, the file system layer accesses the

2000^{th} entry at level 1 of the container file and that indirect block provides the pvbn **20** for fbn **2000**.

In other words, level 1 indirect blocks of the container file contain the pvbns for blocks in the file and, thus, "map" vvbns-to-pvbns of the aggregate. Accordingly, the level 1 indirect blocks of the container file **1000** are configured as a "container map" **1050** for the vvol; there is preferably one container map **1050** per vvol. The container map provides block pointers from fbn locations within the container file to pvbn locations on disk. Furthermore, there is a one-to-one correspondence between fbn locations in the container file and vvbn locations in a vvol.

While the container map **1050** provides a "forward" mapping of vvbn-to-pvbn, an owner map provides a "backward" mapping between pvbn-to-vvbn (and vvid). In particular, mapping metadata of the owner map provides a backward mapping between each pvbn in the aggregate to (i) a vvid that "owns" the pvbn and (ii) the vvbn of the vvol in which the pvbn is located. FIG. **11** is a schematic block diagram of an owner map **1100** that may be advantageously used with the present invention. The owner map **1100** may be embodied as a data structure having a plurality of entries **1110**; there is preferably one entry **1110** for each block in the aggregate.

In the illustrative embodiment, each entry **1110** has a 4-byte vvid and a 4-byte vvbn, and is indexed by a pvbn. That is, for a given block in the aggregate, the owner entry **1110** indicates which vvol owns the block and which pvbn it maps to in the vvbn space, e.g., owner entry **1110** indexed at pvbn **20** has contents vvid **113** and vvbn **2000**. Thus when indexing into the owner map **1100** at pvbn **20**, the file system **580** accesses a vvol having an mode **113** (which is container file **1000**) and then accesses block location **2000** within that file. Each entry **1110** of the owner map **1100** is only valid for blocks that are in use and a vvol only owns those blocks used in the contained file system.

FIG. **12** is a schematic block diagram illustrating an embodiment of an aggregate **1200** that may be advantageously used with the present invention. The aggregate **1200** contains at least one vvol, hereinafter parent vvol **1205**. The parent vvol **1205** comprises a parent container file **1210** (similar to container file **1000**) that is represented as a parent buffer tree having a plurality of blocks in the aggregate, including mode **1212**, level 1 indirect blocks **1214**, which are organized as parent container map **1215** (similar to container map **1050**), and level 0 data blocks **1216**, which comprise all of the blocks used by the parent vvol **1205**, including a volinfo block **1218**. Each block includes one or more pointers that reference (point to) physical blocks located on disk **1220**. In the illustrative hybrid vvol embodiment, the pointers within the vvol are aggregate block numbers, such as pvbns.

As noted, a vvol (such as parent vvol **1205**) generally has the same mode file structure/content as the aggregate, including its own mode file and distinct mode space with corresponding mode numbers, as well as its own root (fsid) directory and subdirectories of files (modes). To that end, the parent vvol **1205** has a volinfo block **1218** that points to one or more fsinfo blocks that, in turn, points to an mode of an mode file that has the same mode structure/content as the aggregate with the exceptions previously noted. The mode for the mode file contains information describing the mode file associated with a file system, such as file system **280**, executing on the parent vvol **1205**. The mode for the mode file may contain a pointer that references (points to) an mode file indirect block containing a set of pointers that reference modes within its root directory. Each mode contains pointers to indirect blocks, such as level 1 indirect blocks and each indirect block includes pointers to level 0 data blocks.

A snapshot can be created from the parent vvol **1205** in accordance with a conventional snapshot mechanism. When the file system **280** generates a parent vvol snapshot (hereinafter "base snapshot" **1235**) of its active file system, an image of the active file system at a point in time (i.e., a consistently point, CP) is "frozen". Note that the base snapshot **1235** is contained within and uses blocks in the parent container file **1210**. As a result, there is no container file for the base snapshot **1235** as the snapshot reuses shared blocks in the vvbn space (and pvbn space) with the parent's active file system. However, for purposes of depiction and ease of description, a "snapshot container file **1240**" is shown and described with respect to FIG. **12**. Yet is should be noted that blocks in the parent container file **1210** are "held down" by the base snapshot **1235** and the clone (described herein) shares the same pvbns. Moreover, the clone uses blocks in the vvbn space for which it has no pointers in its container; this is what keeps the clone from freeing the parent's blocks.

As illustratively shown, the base snapshot **1235** comprises a snapshot container file **1240** (similar to parent container file **1210**) that is represented as a snapshot buffer tree having a plurality of blocks in the aggregate, including mode **1242**, level 1 indirect blocks **1244**, which are organized as snapshot container map **1245** (similar to parent container map **1215**), and level 0 data blocks **1246**, which comprise all of the blocks used by the base snapshot **1235**, including a snapshot volinfo block **1248**. The snapshot volinfo block **1248** is a duplicate copy of the volinfo block **1218** of the parent vvol **1205**. Accordingly, the base snapshot **1235** shares data structures, such as fsinfo blocks, as well as modes, indirect blocks and data blocks of an mode buffer tree, with the active file system on parent vvol **1205**. An instance of the parent vvol "file" in the active file system thus cannot be deleted if the instance of the same file in the snapshot is to be preserved.

In particular, the snapshot mechanism ensures that all blocks of the mode buffer tree remain fixed and all pointers within that buffer tree reference (point to) those fixed blocks. To that end, the physical blocks (pvbns) in the aggregate that are used by the base snapshot **1235** remain fixed and cannot be changed as long as the snapshot persists. In general, when a snapshot is created, all blocks that existed at the CP are prevented from being deleted and/or overwritten in accordance with a snapshot pinning mechanism and any new changes to the blocks in the buffer tree are written elsewhere (to other free blocks). In the case of the base snapshot **1235**, those changes are written to blocks in a vvbn space and in a pvbn space of the aggregate. Although the snapshotted blocks remain intact, any additional changes to the active file system are written in free blocks of the vvbn and pvbn spaces.

With respect to the PCPI pinning mechanism, each PCPI has an associated in-memory "pin counter" variable. Each volume has an in-memory data structure that includes an array containing information about the current snapshots for that volume (one array element per snapshot). Part of each array is the pin counter having a value that is dynamically adjusted and initialized at system boot. Pinning increases the counter by 1 and unpinning decreases the counter by 1. When the value of the pin counter is non-zero, the associated PCPI is regarded as "pinned" (locked) and cannot be deleted.

F. Clone of a Volume

The cloning technique is employed to create a new vvol (e.g., filesystem file), along with a new fsid subdirectory in the aggregate and a new storage label file. The new vvol is embodied as a clone **1350** and comprises an appropriately sized clone container file **1340** represented as a clone buffer tree having a plurality of blocks in the aggregate, including mode **1372**, level 1 indirect blocks **1374**, which are organized as a clone container map **1345** and level 0 data blocks **1376**, which comprise all of the blocks used by the clone. Initially the clone container file **1340** has no (zero) data, i.e., it is entirely sparse, and the container map **1345** is empty. Moreover, a volinfo block for the clone is created that is a slightly modified version of the volinfo block **1248** from the base PCPI **1235**. The modified volinfo block **1352** is written to (store at a level 0 data block of) the container file **1340** of the new vvol clone, i.e., the clone is inserted at the volinfo block location of the new vvol.

It should be noted that the clone container file **1340** only holds all blocks allocated to the clone **1350**. The point of a clone is that is uses blocks "owned" by its parent vvol. The clone container file **1340** has "holes" at the locations of any blocks inherited from the parent vvol. As an example, assume that an indirect block pointer in a file in the parent vvol **1205** contains pvbn **100** and vvbn **200**. Thus, block **200** in the parent container file **1210** is pvbn **100**. In clone **1350**, the indirect block pointers are also pvbn **100** and vvbn **200**, but entry **200** in the clone container file **1340** is zero ("0"), indicating a hole and that the clone inherited its vvbn **200** from the parent vvol. Since entry **200** is 0, the clone "knows" that it could not free the block **100**.

FIG. **13** is a schematic block diagram of an on-disk representation of clone **1350**. The hidden metadata root directory **930** (FIG. **9**) in the aggregate **900** is modified to include a new fsid "clone" subdirectory having at least two new files, filesystem file **1340** and storage label file **1390**: WAFL/fsid "clone"/filesystem file, storage label file. As noted, the storage label file is a small file that functions as an analog to a conventional raid label and, to that end, the new storage label file **1390** includes the name **1392** of the clone **1350**, the online/offline status **1394** of the clone, and other identity and state information **1396** of the associated clone **1350**.

Similarly, the new filesystem file **1340** is a large sparse file that contains all blocks owned by a vvol (clone) and, as such, is also referred to as the container file for the clone. The new filesystem file **1340** includes a block pointer that references a file system embodied as clone **1350**. As a vvol, the clone **1350** has a vvol space with special reserved mode numbers that are used for, among other things, the block allocation bitmap structures. As further described herein, the block allocation bitmap structures, e.g., active map **1362**, summary map **1364** and space map **1366**, are inherited from the base snapshot **1235** (and thus the parent vvol **1205**).

Specifically, the clone **1350** includes a volinfo block **1352** that points to a fsinfo block that, in turn, points to an mode of mode file that has the same mode structure/content as the aggregate with the exceptions previously noted. The mode for the mode file contains information describing the mode file **1360** associated with the file system, such as file system **280**, executing on the clone **1350**. The mode for the mode file may contain a pointer that references (points to) an mode file indirect block containing a set of pointers that reference modes within root directory **1370** of the clone **1350**. Each mode contains pointers to indirect blocks, such as level 1 indirect blocks and each indirect block includes pointers to level 0 data blocks.

Referring also to FIG. **12**, the PCPI volinfo block **1248** from the base PCPI **1235** is inserted as a level 0 data block (volinfo block **1352**) within the container file **1340** on the clone. The volinfo block **1352** is a slightly modified version of the PCPI volinfo block **1248**; for example, the volinfo block **1352** is modified to delete all PCPIs (fsinfo blocks) other than fsinfo block **1354** for the base PCPI **1235**. The inherited summary map **1364** is also modified to reflect that all non-cloned snapshots have been removed (deleted) from the clone. The modified volinfo block **1352** is thus substantially similar to PCPI volinfo block **1248** and, to that end, essentially incorporates the base PCPI into the clone; accordingly the base PCPI (and its associated safeguards) protects the snapshotted blocks from being overwritten. All new changes are written to block locations in the vvbn and pvbn spaces of the base PCPI that are not used and, thus, cannot interfere with the clone.

Since the modified volinfo block **1352** forms the root of a modified volinfo buffer tree that is similar to a parent volinfo block buffer tree of its parent vvol **1205**, all blocks of the parent volinfo block buffer tree can be accessed when traversing the modified volinfo block buffer tree. In other words, the PCPI volinfo block **1248** stored in a level 0 block of the PCPI container file **1240** (actually the parent's container file **1210**) contains pointers that reference other blocks of its buffer tree stored in other level 0 blocks **1246** (**1216**) of the container file **1240** (**1210**). The pointers within the volinfo block **1248** to the other level 0 blocks **1246** are physical pointers (pvbns) that reference physical block locations on disk **1220**. Those parent (PCPI) volinfo buffer tree blocks can be accessed through the modified volinfo block **1352** of the clone **1350** in the same manner as traversing the PCPI container file tree **1240** because the blocks within the modified volinfo block buffer tree are the physical blocks represented by the level 0 data blocks **1246** in the PCPI container file **1240**.

The clone **1350** may then be instantiated by, e.g., loading a file system associated with the new vvol onto the clone and bringing the clone "online", with the only blocks owned by the clone comprising its modified volinfo block. The file system, such as file system **280**, executes on the clone as it would on a typical vvol, such as the parent vvol. In fact, the file system within the clone resembles the file system within the base PCPI, since they comprise substantially the same blocks on disk. The resulting clone **1350** is thus a "full-fledged" vvol, i.e., it can service storage (read and write) requests and has its own logical properties, such as snapshot operation functionality, that enables the clone to be snapshotted, snap restored, snapmirrored and otherwise manipulated as any other vvol. A restriction is that the base PCPI **1235** cannot be deleted in the parent vvol **1205** while the clone exists. As a result, the cloning technique enables the clone and parent vvol to share on-disk blocks of data in a zero-copy fashion, similar to a conventional PCPI, while also allowing for modifications (unlike the conventional PCPI).

Notably, a fundamental property of the cloning technique is that the base PCPI **1235** is common among the clone **1350** and its parent vvol **1205** and, thus, cannot be deleted or freed in the parent vvol while the clone exists. That is, all blocks shared between the clone and its parent vvol are blocks within that base PCPI and, thus, neither may attempt to free or delete those blocks. This restriction also precludes any operation that implicitly makes the PCPI disappear. However, the restriction may be relaxed to allow the clone to "free" the PCPI; freeing of the PCPI requires checking of the owner map **1100** by block free operations on the clone to determine whether the clone or parent owns the block in the aggregate. The clone may only return a block to the aggregate if it owned the block, not if it was inherited from the parent. However in the dual vbn embodiment, reference is made directly to the clone container file **1340** to determine the owner of the block.

Since the modified volinfo block **1352** references physical block locations in the aggregate that cannot be deleted (because they are held down by the base PCPI **1235** in the parent vvol **1205**), when the clone **1350** comes online, it functions in a manner similar to that of a snap restore arrangement. That is, the modified volinfo block **1352** of the clone references a PCPI at a particular point in time (i.e. the base PCPI **1235**) and the clone restores the state of the active file system as represented by that PCPI. The difference between a clone and a conventional PCPI is that write allocation can be performed on the clone that essentially allows changes to the base PCPI.

When changes are made to the clone (i.e., blocks of the base snapshot **1235**), those changes are written out (stored) according to an extended write allocation technique employed by the file system. The extended write allocation technique is described in U.S. Pat. No. 7,430,571 titled, EXTENSION OF WRITE ANYWHERE FILE LAYOUT WRITE ALLOCATION, issued on Sep. 30, 2008. Broadly stated, a write allocator **282** (FIG. **2**) selects a pvbn in the aggregate for a newly allocated block and selects a vvbn in the clone for that new block using appropriate block allocation bitmaps for both the pvbn and vvbn spaces. As noted, the container file **1340** on the clone **1350** initially has no data other than the modified volinfo block **1352**. As write operations occur into the clone, the file system **280** fills in the level 0 blocks **1376** of the container file **1340** with the changes associated with those write operations.

As further noted, the block allocation bitmaps used by the file system to select the vvbn are inherited from the base PCPI. By inheriting the base PCPI's bitmaps, the file system executing on the clone also inherits the PCPI's vvbn space; any changes made to the clone are thus directed to "empty" or unused blocks in that inherited vvbn space. This avoids any collisions with the blocks in the base PCPI **1235**. However, the inherited vvbn space diverges from the vvbn space of the base PCPI at the time the clone is created. Therefore, as changes are made to the clone, the container file **1340** on the clone starts filling in its level 0 blocks in accordance with the extended write allocation technique. Although the base PCPI and clone now have separate vvbn spaces, some of the vvbns that are used in both spaces reference the same physical blocks in the aggregate.

As noted, a parent vvol, such as parent vvol **1205**, includes a container file, such as container file **1210**, having a plurality of blocks, such as mode **1212**, level 1 indirect blocks **1214** and level 0 data blocks **1216**. A clone, such as clone **1350**, may be created from a base snapshot **1235** of the parent vvol **1205** in accordance with the cloning technique described herein. The parent and clone have the same sized vbn space and, initially, all blocks (other than the modified volinfo block **1352**) of container file **1340** of the clone **1350** are shared with the parent vvol **1205** (and/or base snapshot **1235**). The clone splitting technique essentially "splits" those shared blocks between the parent vvol (base snapshot) and the clone to thereby enable the clone to become a full fledged, independent volume.

FIG. **14** is a schematic block diagram illustrating an illustrative clone-splitting technique **1400**. As also noted, the clone **1350** includes, among other things, an mode file **1360**. All modes **1412** of the file system (executing on the clone) are organized into the mode file **1360**. Each mode **1412** forms the root of an mode buffer tree **1410** and contains pointers to indirect blocks, such as level 1 (L1) indirect blocks **1414** and each indirect block includes pointers to level 0 (L0) data blocks **1416**. A clone scanner **1450** scans (traverses) the entire mode buffer tree **1410** of each mode **1412** and determines whether to initiate writing of a new copy of a block used in the clone to a level 0 data block **1376** of the clone container file **1340**; as described herein, this determination is dependent upon whether the block is not owned by the clone. The clone scanner **1450** is illustratively an mode-based file system scanner configured to run over an online volume, such as clone **1450**, to thereby enable access to the clone during the shared block splitting procedure.

It should be noted that a clone may be created on a clone (a nesting arrangement of clones). Thus, it is not adequate to check for parent vvol ownership of a block used by the clone. Specifically, the clone splitting technique requires that the block used by the clone not be owned by the clone. Accordingly, the clone scanner **1450** efficiently examines all blocks used in the clone to determine those which are not owned by the clone **1350**. Those blocks that are not owned by the clone are copied to the clone (e.g., in accordance with a copy-on-write operation) to essentially "split" the blocks shared between the parent vvol **1205** and clone **1350**.

In the illustrative embodiment, the clone splitting technique is implemented as a multi-phase process comprising a first "validity checking" phase, a second "clone split scanner" phase and a third "clean-up" phase. Specifically, the first phase of the clone splitting technique involves checking the validity of the scan, including clone state. Validity checking includes ensuring that there are no pinned PCPI on the clone itself. If there are pinned PCPIs, the split operation procedure is rejected because such an operation removes all snapshots and no pinned snapshots should be removed, e.g., from clones of the clone. If no errors are found, the clone transitions to a persistent "clone_split" state that allows continuation of clone splitting after an unexpected system failure, such as panic or power failure.

The second clone split scanner phase of the clone splitting technique comprises the shared block splitting procedure for splitting blocks shared between a clone and parent vvol. FIG. **15** is a flowchart illustrating the shared block splitting procedure **1500**. The procedure starts at step **1505** and proceeds to step **1510** where the clone scanner scans (examines) all the modes of the mode file in the clone and, for each inode, "walks" the inode buffer tree searching for L1 blocks (step **1515**). Upon discovering each L1 block, in step **1520** the clone scanner examines each pointer in the L1 block to a L0 data block and, in step **1525**, determines the owner of that L0 block. The pointers are illustratively physical volume block numbers (pvbns) and the owner map **1100** in the aggregate is illustratively used to determine the owner of a particular pvbn block.

If the owner map **1100** indicates the clone is the owner of the L0 block (step **1530**), the clone scanner does not perform any further operation on that data block (step **1535**) and the procedure ends at step **1550**. However if the owner map indicates that the clone is not the owner of the L0 block, the scanner loads the block into memory **124** (buffer cache **170**) and marks it as "dirty" (step **1540**). In step **1545**, the write allocator **282** of the file system **280** is invoked to write allocate the dirty block to a new block that is owned by the clone. That is, the write allocator performs a copy-on-write operation that essentially loads the dirty block into the new block without altering its data contents, thereby furthering "filling" of the container file **1340** of the clone. The procedure then ends at step **1550**.

As can be appreciated, the splitting of blocks shared between a clone and its parent may, in some cases, consume substantial disk storage space (e.g., up to 100% of the clone disk size). For a large vvol, this presents a possibility that the clone splitting technique may fail due to lack of disk space. As noted, previously an administrator would manually estimate the amount of storage space required prior to initiating a clone splitting operation. If that estimate was incorrect and there was not sufficient storage available, not only would the operation fail, but the administrator would not be informed of the failed operation for some time (on the order of hours).

G. Calculation of Storage Required to Split a Clone

The present invention is directed to a system and method for efficiently calculating an estimated amount of storage required to split a clone volume from its parent volume. The system and method is illustratively embodied as a command line interface (CLI) command, i.e., a clone split estimate command, executed by the estimation module **295** of storage system **120**. Notably, the estimation module **295** cooperates with the file system **280** to quickly access data structures containing information used to perform the storage calculation without the need to access each block of the clone and parent volumes. To that end, the clone split estimate command is issued through the UI **275** of the storage operating system **200** by a system administrator. The novel command is then processed by the estimation module **295** to generate appropriate file system operations needed to interact with the file system **280**.

FIG. **16** is a flowchart detailing the steps of a procedure **1600** for calculating an estimated amount of storage required to perform a clone splitting operation in accordance with an embodiment of the present invention. The procedure **1600** begins in step **1605** and continues to step **1610** where administrator issues the clone split estimate command to the estimation module **295** of storage system **120** illustratively via a CLI of the UI **275**. Alternately, the administrator may utilize a graphical user interface (GUI) of the UI **275** to essentially select the novel command for execution by the estimation module **295**.

In step **1615**, the estimation module **295** processes the command by interacting with the file system **280** to retrieve the size (i.e., the number of blocks) of the clone volume. Illustratively, the clone volume size may be obtained by examining metadata of a file system information data structure, e.g., the fsinfo block **1354**, associated with the clone volume **1350**. In step **1620**, estimation module interacts with the file system **280** to retrieve the number of blocks stored in a container file for the clone volume using, e.g., conventional file system operations directed to the container file **1340** of the clone **1350**. Additionally, in an alternate embodiment as indicated in step **1625**, the estimation module **295** may access an "in-memory" construct associated with a non-volatile random access memory (not shown) of the storage system **120** to determine the number of blocks to be written to the container file **1340** at a next consistency point, i.e., blocks that are currently in buffer cache **170**. Note that these blocks to be written to the container file represent data that has been written to the clone, but not yet committed to disk due to the log structured nature of the file system.

In step **1630**, the estimation module **295** calculates the estimated amount of storage required for the clone splitting operation. Illustratively, the estimation module calculates the estimated storage space (i.e., number of blocks) required by subtracting the size (i.e., number of blocks) in the container file from the size (i.e., number of blocks) of the clone volume. For example, if is determined that the clone volume is 800 GB in size and 200 GB of data has been written in the container file, then the amount of space required is approximately 600 GB. Alternately, the calculation may involve subtracting the number of blocks in the container file and the number of blocks to be written to the container file from the number of blocks of the clone. Moreover, a determination may be made to account for the appropriate number of indirect blocks required to accommodate the level 0 data blocks of a certain size.

The result of the calculation thus estimates the amount of storage space required to perform a clone splitting operation, i.e., the number of blocks stored in the parent volume of the clone (or parent's parent, etc.) that must be written during the clone splitting operation. In step **1635**, the estimated amount of storage space is displayed to the administrator so that appropriate disk provisioning may occur before the initiation of the clone splitting operation. For example, if the results of procedure **1600** indicate that approximately 600 GB of data will be written during the clone split operation, the administrator can ensure that there is at least 600 GB of disk space available for the split clone operation. The procedure then completes in step **1640**.

The foregoing description has been directed to specific embodiments of this invention. It will be apparent, however, that other variations and modifications may be made to the described embodiments, with the attainment of some or all of their advantages. For instance, it is expressly contemplated that the teachings of this invention can be implemented as software (including a computer-readable medium having program instructions executing on a computer), hardware, firmware, or a combination thereof. Accordingly this description is to be taken only by way of example and not to otherwise limit the scope of the invention. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

What is claimed is:

1. A computer implemented method, comprising:

determining a first amount of data stored in a data container of a clone volume stored on a storage device operatively connected to a computer, the data stored in the data container configured as modified data of the clone volume, the clone volume configured to share unmodified data with a parent volume;

determining a size of the clone volume by examining metadata of a data structure associated with the clone volume; and

determining a second amount of the unmodified data shared by the parent volume based on the first amount of data stored in the data container and the size of the clone volume.

2. The computer implemented method of claim **1** wherein the data structure comprises a file system information block.

3. The computer implemented method of claim **1** further comprising displaying the second amount of the unmodified data shared by the parent volume to a user.

4. The computer implemented method of claim **1** further comprising provisioning the computer to accommodate the second amount of the unmodified data shared by the parent volume.

5. The computer implemented method of claim **1** wherein determining the first amount of data stored in the data container further comprises determining a third amount of data to be written to the data container during a consistency point.

6. The computer implemented method of claim **5** wherein determining the first amount of data stored in the data container further comprises subtracting from the size of the clone volume the third amount of data to be written to the data container during the consistency point.

7. The computer implemented method of claim **5** wherein determining the third amount of data to be written to the data container during the consistency point comprises accessing an in-memory construct associated with a memory of the computer.

8. The computer implemented method of claim **1** wherein determining the second amount of the unmodified data shared by the parent volume comprises subtracting the first amount of data stored in the data container from the size of the clone volume.

9. The computer implemented method of claim **1** wherein at least some of the data stored in the data container is configured as data blocks.

10. The computer implemented method of claim **1** wherein the second amount of the unmodified data shared by the parent volume is a fourth amount of storage space required to split the clone volume from the parent volume.

11. A non-transitory computer readable storage medium containing executable program instructions configured to be executed by a processor and further configured to be stored on the computer readable storage medium, the computer readable storage medium comprising:

program instructions that determine a first amount of data stored in a data container of a clone volume stored on a storage device operatively connected to a computer, the data stored in the data container configured as modified data of the clone volume, the clone volume configured to share unmodified data with a parent volume;

program instructions that determine a size of the clone volume by examining metadata of a data structure associated with the clone volume; and

program instructions that determine a second amount of the unmodified data shared by the parent volume based on the first amount of data stored in the data container and the size of the clone volume.

12. The non-transitory computer readable storage medium of claim **11** wherein the data structure comprises a file system information block.

13. The non-transitory computer readable storage medium of claim **11** further comprising program instructions that display the second amount of the unmodified data shared by the parent volume to a user.

14. The non-transitory computer readable storage medium of claim **11** further comprising program instructions that provision the computer to accommodate the second amount of the unmodified data shared by the parent volume.

15. The non-transitory computer readable storage medium of claim **11** wherein the program instructions that determine the first amount of data stored in the data container further comprise program instructions that determine a third amount of data to be written to the data container during a consistency point.

16. The non-transitory computer readable storage medium of claim **15** wherein the program instructions that determine the first amount of data stored in the data container further comprise program instructions that subtract from the size of the clone volume the third amount of data to be written to the data container during the consistency point.

17. The non-transitory computer readable storage medium of claim **15** wherein the program instructions that determine the third amount of data to be written to the data container during the consistency point comprises program instructions that access an in-memory construct associated with a memory of the computer.

18. The non-transitory computer readable storage medium of claim **11** wherein the program instructions that determine the second amount of the unmodified data shared by the parent volume further comprise program instructions that subtract the first amount of data stored in the data container from the size of the clone volume.

19. The non-transitory computer readable storage medium of claim **11** wherein at least some of the data stored in the data container is configured as data blocks.

20. The non-transitory computer readable storage medium of claim **11** wherein the second amount of the unmodified data shared by the parent volume is a fourth amount of storage space required to split the clone volume from the parent volume.

21. A computer data storage system, comprising:

a processor of the computer data storage system configured to create a clone volume stored on a storage device operatively connected to the computer data storage system, the clone volume comprising a first amount of data stored in a data container of the clone volume, the data stored in the data container configured as modified data of the clone volume, the clone volume configured to share unmodified data with a parent volume;

the processor further configured to execute a process configured to determine a size of the clone volume by examining metadata of a data structure associated with the clone volume; and

the processor further configured to determine a second amount of the unmodified data shared by the parent volume based on the first amount of data stored in the data container and the size of the clone volume.

22. The computer data storage system of claim **21** wherein the data structure comprises a file system information block.

23. The computer data storage system of claim **21** further comprising a display operatively connected to the computer data storage system configured to display the second amount of the unmodified data shared by the parent volume to a user.

24. The computer data storage system of claim **21** wherein the process is further configured to determine the first amount of data stored in the data container by determining a third amount of data to be written to the data container during a consistency point.

25. The computer data storage system of claim **24** wherein the process is further configured to access an in-memory construct associated with a memory of the computer data storage system to determine the third amount of data to be written to the data container during a consistency point.

26. The computer data storage system of claim **24** wherein the process is further configured to determine the first amount of data stored in the data container by subtracting from the size of the clone volume the third amount of data to be written to the data container during the consistency point.

27. The computer data storage system of claim **21** wherein the process is further configured to determine the second amount of the unmodified data shared by the parent volume by subtracting the first amount of data stored in the data container from the size of the clone volume.

28. The computer data storage system of claim **21** wherein at least some of the data stored in the data container is configured as data blocks.

29. The computer data storage system of claim **21** wherein the second amount of the unmodified data shared by the parent volume is a fourth amount of storage space required to split the clone volume from the parent volume.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,152,503 B1
APPLICATION NO. : 12/783664
DATED : October 6, 2015
INVENTOR(S) : Robert L. Fair

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 4, Line 19:
Reads: system mode structure;
Should read: system inode structure;

Column 4, Line 21:
Reads: system mode structure of FIG. **3** including a persistent con-
Should read: system inode structure of FIG. **3** including a persistent con-

Column 4, Line 22:
Reads: sistency point image (PCPI) mode;
Should read: sistency point image (PCPI) inode;

Column 4, Line 24:
Reads: system mode structure of FIG. **4** after a data block has been
Should read: system inode structure of FIG. **4** after a data block has been

Column 4, Line 26:
Reads: FIG. **6** is a schematic block diagram of an mode that may be
Should read: FIG. **6** is a schematic block diagram of an inode that may be

Column 7, Line 41:
Reads: byte (kB) blocks and using index nodes (“modes”) to identify
Should read: byte (kB) blocks and using index nodes (“inodes”) to identify

Column 7, Line 45:
Reads: metadata files include, among others, an mode file. A file
Should read: metadata files include, among others, an inode file. A file

Signed and Sealed this
Tenth Day of January, 2017

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office

Column 7, Line 46:
Reads: handle, i.e., an identifier that includes an mode number, is
Should read: handle, i.e., an identifier that includes an inode number, is

Column 7, Line 47:
Reads: used to retrieve an mode from disk
Should read: used to retrieve an inode from disk

Column 7, Line 48:
Reads: Broadly stated, all modes of the write-anywhere file system
Should read: Broadly stated, all inodes of the write-anywhere file system

Column 7, Line 49:
Reads: are organized into the mode file. A file system (FS) info block
Should read: are organized into the inode file. A file system (FS) info block

Column 7, Line 51:
Reads: includes an mode of a file that includes all other modes of the
Should read: includes an inode of a file that includes all other inodes of the

Column 7, Line 54:
Reads: a RAID group. The mode of the mode file may directly
Should read: a RAID group. The inode of the inode file may directly

Column 7, Line 55:
Reads: reference (point to) blocks of the mode file or may reference
Should read: reference (point to) blocks of the inode file or may reference

Column 7, Line 56:
Reads: indirect blocks of the mode file that, in turn, reference direct
Should read: indirect blocks of the inode file that, in turn, reference direct

Column 7, Line 57:
Reads: blocks of the mode file. Within each direct block of the mode
Should read: blocks of the inode file. Within each direct block of the inode

Column 7, Line 58:
Reads: file are embedded modes, each of which may reference indi-
Should read: file are embedded inodes, each of which may reference indi-

Column 8, Line 3:
Reads: the file system **280** indexes into the mode file using the mode
Should read: the file system **280** indexes into the inode file using the inode

Column 9, Line 60:
Reads: plary file system mode structure **300** shown in FIG. 3. The
Should read: plary file system inode structure **300** shown in FIG. 3. The

Column 9, Line 61:
Reads: mode for an mode file **305** contains information describing
Should read: inode for an inode file **305** contains information describing

Column 9, Line 62:
Reads: the mode file associated with a file system. In this exemplary
Should read: the inode file associated with a file system. In this exemplary

Column 9, Line 63:
Reads: file system mode structure, the mode for the mode file **305**
Should read: file system inode structure, the inode for the inode file **305**

Column 9, Line 64:
Reads: contains a pointer that references (points to) an mode file
Should read: contains a pointer that references (points to) an inode file

Column 9, Line 65:
Reads: indirect block **310**. The mode file indirect block **310** contains
Should read: indirect block **310**. The inode file indirect block **310** contains

Column 9, Line 66:
Reads: a set of pointers that reference mode file blocks, each of which
Should read: a set of pointers that reference inode file blocks, each of which

Column 9, Line 67:
Reads: contains an array of modes **317**, which in turn contain point-
Should read: contains an array of inodes **317**, which in turn contain point-

Column 10, Line 6:
Reads: system, a PCPI mode is generated as shown in FIG. **4**. The
Should read: system, a PCPI inode is generated as shown in FIG. **4**. The

Column 10, Line 7:
Reads: PCPI mode **405** is, in essence, a duplicate copy of the mode
Should read: PCPI inode **405** is, in essence, a duplicate copy of the inode

Column 10, Line 8:
Reads: for the mode file **305** of the file system mode structure **300**
Should read: for the inode file **305** of the file system inode structure **300**

Column 10, Line 9:
Reads: that shares common parts, such as modes and blocks, with the
Should read: that shares common parts, such as inodes and blocks, with the

Column 10, Line 11:
Reads: mode structure **400** includes the mode file indirect blocks
Should read: inode structure **400** includes the inode file indirect blocks

Column 10, Line 12:
Reads: **310**, modes **317**, indirect blocks **319** and file data blocks
Should read: **310**, inodes **317**, indirect blocks **319** and file data blocks

Column 10, Line 16:
Reads: **5** shows an exemplary file system mode structure **500** after a
Should read: **5** shows an exemplary file system inode structure **500** after a

Column 10, Line 23:
Reads: mode **317** must be rewritten. Similarly, the mode file indirect
Should read: inode **317** must be rewritten. Similarly, the inode file indirect

Column 10, Line 24:
Reads: block **310** and the mode for the mode file **305** must be rewrit-
Should read: block **310** and the inode for the inode file **305** must be rewrit-

Column 10, Line 27:
Reads: mode **405** contains a pointer to the original mode file indirect
Should read: inode **405** contains a pointer to the original inode file indirect

Column 10, Line 28:
Reads: block **110** which, in turn, contains pointers through the mode
Should read: block **110** which, in turn, contains pointers through the inode

Column 10, Line 39:
Reads: arrangement of the active file system. A new mode for the
Should read: arrangement of the active file system. A new inode for the

Column 10, Line 40:
Reads: mode file **305** is established representing the new structure
Should read: inode file **305** is established representing the new structure

Column 10, Line 44:
Reads: from all snapshots. Thus, while the active file system mode
Should read: from all snapshots. Thus, while the active file system inode

Column 10, Line 45:
Reads: for the mode file **305** points to new blocks **310**, **317**, **319**,
Should read: for the inode file **305** points to new blocks **310**, **317**, **319**,

Column 11, Line 24:
Reads: write-anywhere file system as an mode data structure adapted
Should read: write-anywhere file system as an inode data structure adapted

Column 11, Line 26:
Reads: diagram of an mode **600**, which preferably includes a meta-
Should read: diagram of an inode **600**, which preferably includes a meta-

Column 11, Line 28:
Reads: stored in the metadata section **610** of each mode **600** describes
Should read: stored in the metadata section **610** of each inode **600** describes

Column 11, Line 33:
Reads: of the file. The contents of the data section **650** of each mode,
Should read: of the file. The contents of the data section **650** of each inode,

Column 11, Line 35:
Reads: type of file (mode) defined within the type field **612**. For
Should read: type of file (inode) defined within the type field **612**. For

Column 11, Line 36:
Reads: example, the data section **650** of a director mode contains
Should read: example, the data section **650** of a director inode contains

Column 11, Line 38:
Reads: tion of a regular mode contains file system data. In this latter
Should read: tion of a regular inode contains file system data. In this latter

Column 11, Line 41:
Reads: Specifically, the data section **650** of a regular on-disk mode
Should read: Specifically, the data section **650** of a regular on-disk inode

Column 11, Line 47:
Reads: of the mode, file system data having a size that is less than or
Should read: of the inode, file system data having a size that is less than or

Column 11, Line 49:
Reads: section of that mode. However, if the file system data is
Should read: section of that inode. However, if the file system data is

Column 11, Line 51:
Reads: data section of the mode (e.g., a first level mode) comprises up
Should read: data section of the inode (e.g., a first level inode) comprises up

Column 11, Line 56:
Reads: the data section **650** of the mode (e.g., a second level mode)
Should read: the data section **650** of the inode (e.g., a second level inode)

Column 11, Line 60:
Reads: 64 MB, each pointer in the data section **650** of the mode (e.g.,
Should read: 64 MB, each pointer in the data section **650** of the inode (e.g.,

Column 11, Line 61:
Reads: a third level mode) references a double indirect block (e.g., a
Should read: a third level inode) references a double indirect block (e.g., a

Column 12, Line 1:
Reads: When an on-disk mode (or block) is loaded from disk **130**
Should read: When an on-disk inode (or block) is loaded from disk **130**

Column 12, Line 4:
Reads: surrounding the mode **600** indicates the in-core representa-
Should read: surrounding the inode **600** indicates the in-core representa-

Column 12, Line 5:
Reads: tion of the on-disk mode structure. The in-core structure is a
Should read: tion of the on-disk inode structure. The in-core structure is a

Column 12, Line 9:
Reads: “dirty” bit **660**. After data in the mode (or block) is updated/
Should read: “dirty” bit **660**. After data in the inode (or block) is updated/

Column 12, Line 11:
Reads: data is marked “dirty” using the dirty bit **660** so that the mode
Should read: data is marked “dirty” using the dirty bit **660** so that the inode

Column 12, Line 14:
Reads: tem, including the modes and mode file, are disclosed and
Should read: tem, including the inodes and inode file, are disclosed and

Column 12, Line 25:
Reads: level) mode **702**, such as an embedded mode, references
Should read: level) inode **702**, such as an embedded inode, references

Column 12, Line 27:
Reads: mode) contain pointers **705** that ultimately reference data
Should read: inode) contain pointers **705** that ultimately reference data

Column 12, Line 51:
Reads: of only the pvbn in the parent indirect block (e.g., mode or
Should read: of only the pvbn in the parent indirect block (e.g., inode or

Column 12, Line 57:
Reads: of which, in turn, "points to" an mode file and its correspond-
Should read: of which, in turn, "points to" an inode file and its correspond-

Column 12, Line 58:
Reads: ing mode buffer tree. The read path on a vvol is generally the
Should read: ing inode buffer tree. The read path on a vvol is generally the

Column 13, Line 51:
Reads: block pointer to an mode file **906** that contains modes of a
Should read: block pointer to an inode file **906** that contains inodes of a

Column 13, Line 54:
Reads: other special metadata files. The mode file **906** further
Should read: other special metadata files. The inode file **906** further

Column 13, Line 66:
Reads: gate **900** maintains these vvols **950** at special reserved mode
Should read: gate **900** maintains these vvols **950** at special reserved inode

Column 13, Line 67:
Reads: numbers. Each vvol **950** also has special reserved mode num-
Should read: numbers. Each vvol **950** also has special reserved inode num-

Column 14, Line 5:
Reads: Specifically, each vvol **950** has the same mode file struc-
Should read: Specifically, each vvol **950** has the same inode file struc-

Column 14, Line 13:
Reads: Each fsinfo block, in turn, points to an mode file **960** that, as
Should read: Each fsinfo block, in turn, points to an inode file **960** that, as

Column 14, Line 14:
Reads: noted, has the same mode structure/content as the aggregate
Should read: noted, has the same inode structure/content as the aggregate

Column 14, Line 16:
Reads: mode file **960** and distinct mode space with corresponding
Should read: inode file **960** and distinct inode space with corresponding

Column 14, Line 17:
Reads: mode numbers, as well as its own root (fsid) directory **970** and
Should read: inode numbers, as well as its own root (fsid) directory **970** and

Column 14, Line 50:
Reads: and has an mode **1002** that is assigned an mode number equal
Should read: and has an inode **1002** that is assigned an inode number equal

Column 14, Line 52:
Reads: **1000** has an mode number **113**. The container file is essen-
Should read: **1000** has an inode number **113**. The container file is essen-

Column 15, Line 31:
Reads: **1000** has an mode number **113**. The container file is essen-
Should read: **1000** has an inode number **113**. The container file is essen-

Column 15, Line 43:
Reads: mode **1212**, level 1 indirect blocks **1214**, which are organized
Should read: inode **1212**, level 1 indirect blocks **1214**, which are organized

Column 15, Line 52:
Reads: the same mode file structure/content as the aggregate, includ-
Should read: the same inode file structure/content as the aggregate, includ-

Column 15, Line 53:
Reads: ing its own mode file and distinct mode space with corre-
Should read: ing its own inode file and distinct inode space with corre-

Column 15, Line 54:
Reads: sponding mode numbers, as well as its own root (fsid) direc-
Should read: sponding inode numbers, as well as its own root (fsid) direc-

Column 15, Line 55:
Reads: tory and subdirectories of files (modes). To that end, the
Should read: tory and subdirectories of files (inodes). To that end, the

Column 15, Line 57:
Reads: or more fsinfo blocks that, in turn, points to an mode of an
Should read: or more fsinfo blocks that, in turn, points to an inode of an

Column 15, Line 58:
Reads: mode file that has the same mode structure/content as the
Should read: inode file that has the same inode structure/content as the

Column 15, Line 59:
Reads: aggregate with the exceptions previously noted. The mode for
Should read: aggregate with the exceptions previously noted. The inode for

Column 15, Line 60:
Reads: the mode file contains information describing the mode file
Should read: the inode file contains information describing the inode file

Column 15, Line 62:
Reads: ing on the parent vvol **1205**. The mode for the mode file may
Should read: ing on the parent vvol **1205**. The inode for the inode file may

Column 15, Line 63:
Reads: contain a pointer that references (points to) an mode file
Should read: contain a pointer that references (points to) an inode file

Column 15, Line 65:
Reads: modes within its root directory. Each mode contains pointers
Should read: inodes within its root directory. Each inode contains pointers

Column 16, Line 22:
Reads: plurality of blocks in the aggregate, including mode **1242**,
Should read: plurality of blocks in the aggregate, including inode **1242**,

Column 16, Line 30:
Reads: such as fsinfo blocks, as well as modes, indirect blocks and
Should read: such as fsinfo blocks, as well as inodes, indirect blocks and

Column 16, Line 31:
Reads: data blocks of an mode buffer tree, with the active file system
Should read: data blocks of an inode buffer tree, with the active file system

Column 16, Line 36:
Reads: blocks of the mode buffer tree remain fixed and all pointers
Should read: blocks of the inode buffer tree remain fixed and all pointers

Column 17, Line 2:
Reads: mode **1372**, level 1 indirect blocks **1374**, which are organized
Should read: inode **1372**, level 1 indirect blocks **1374**, which are organized

Column 17, Line 42:
Reads: has a vvol space with special reserved mode numbers that are
Should read: has a vvol space with special reserved inode numbers that are

Column 17, Line 49:
Reads: that points to a fsinfo block that, in turn, points to an mode of
Should read: that points to a fsinfo block that, in turn, points to an inode of

Column 17, Line 50:
Reads: mode file that has the same mode structure/content as the
Should read: inode file that has the same inode structure/content as the

Column 17, Line 51:
Reads: aggregate with the exceptions previously noted. The mode for
Should read: aggregate with the exceptions previously noted. The inode for

Column 17, Line 52:
Reads: the mode file contains information describing the mode file
Should read: the inode file contains information describing the inode file

Column 17, Line 54:
Reads: executing on the clone **1350**. The mode for the mode file may
Should read: executing on the clone **1350**. The inode for the inode file may

Column 17, Line 55:
Reads: contain a pointer that references (points to) an mode file
Should read: contain a pointer that references (points to) an inode file

Column 17, Line 57:
Reads: modes within root directory **1370** of the clone **1350**. Each
Should read: inodes within root directory **1370** of the clone **1350**. Each

Column 17, Line 58:
Reads: mode contains pointers to indirect blocks, such as level 1
Should read: inode contains pointers to indirect blocks, such as level 1

Column 19, Line 41:
Reads: of blocks, such as mode **1212**, level 1 indirect blocks **1214** and
Should read: of blocks, such as inode **1212**, level 1 indirect blocks **1214** and

Column 19, Line 55:
Reads: clone **1350** includes, among other things, an mode file **1360**.
Should read: clone **1350** includes, among other things, an inode file **1360**.

Column 19, Line 56:
Reads: All modes **1412** of the file system (executing on the clone) are
Should read: All inodes **1412** of the file system (executing on the clone) are

Column 19, Line 57:
Reads: organized into the mode file **1360**. Each mode **1412** forms the
Should read: organized into the inode file **1360**. Each inode **1412** forms the

Column 19, Line 58:
Reads: root of an mode buffer tree **1410** and contains pointers to
Should read: root of an inode buffer tree **1410** and contains pointers to

Column 19, Line 62:
Reads: mode buffer tree **1410** of each mode **1412** and determines
Should read: inode buffer tree **1410** of each inode **1412** and determines

Column 19, Line 67:
Reads: scanner **1450** is illustratively an mode based file system scan-
Should read: scanner **1450** is illustratively an inode based file system scan-

Column 20, Line 36:
Reads: modes of the mode file in the clone and, for each inode,
Should read: inodes of the inode file in the clone and, for each inode,